SORGHUM
IN THE EIGHTIES

Volume 2

International Crops Research Institute for the Semi-Arid Tropics

Sorghum in the Eighties

Proceedings of the
International Symposium on Sorghum

Volume 2

2-7 November 1981, ICRISAT Center
Patancheru, A.P., India

Sponsored by

USAID Title XII Collaborative Research Support Program
on Sorghum and Pearl Millet
(INTSORMIL)

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Foreword

In October 1971 in Hyderabad, India an international symposium on sorghum was held which examined and reviewed the then scientific, production, and nutritional knowledge of sorghum as a crop and as a human food.

Almost exactly 10 years later, ICRISAT hosted Sorghum in the Eighties—an international symposium sponsored by USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (INTSORMIL); the Indian Council of Agricultural Research (ICAR); and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

It was felt by the organizers that because so much knowledge and information had been attained in the intervening 10 years, scientists should meet again. Consequently, 245 scientists from 37 countries attended the Symposium from 2 to 7 November 1981 at ICRISAT Center near Hyderabad. They examined and evaluated the achievements made in the last decade, discussed the current problems, and made recommendations for future research and other activities.

The participants showed a critical awareness of sorghum's role as an important cereal for food, feed, construction material, and fuel in the developed and the developing countries. On a world production and utilization basis, sorghum ranks fifth after wheat, rice, maize and barley. About 90% of the total production and 90% of the harvested area are located in 12 countries in Asia, the Americas, Africa, and Oceania.

Sorghum is one of the main staple food grains of the world's poorest people, particularly in the semi-arid tropics (SAT). Over 55% of world sorghum production is in the SAT. Of the total SAT production, Asia and Africa contribute about 65%, of which 34% is harvested in India. Matters of considerable concern are that sorghum production is growing more slowly than population and that the food situation in parts of Africa is rapidly deteriorating.

Situations such as these clearly indicate that more socioeconomic factors will need to be taken into account to guide and influence the direction of future scientific research on sorghum. The deliberations and discussions during the Symposium on factors related to sorghum and its environment, including climate, insects, fungi, and birds; the genetic resources; breeding for improvement; production technology; food quality and utilization; and the socioeconomic issues showed that many studies will still have to be made to further unravel the potentialities of this cereal. Sharp notice has been taken of research fields where there has been little progress in the last 10 years.

A main value of the Symposium has been to determine work priorities for ICRISAT and the national programs in the SAT, and to emphasize the need for continued cooperation with other institutions. Sorghum in the Eighties has been a rewarding Symposium which has not lost sight of the basic objective to increase the yield and production of better sorghum to feed people.

I believe that the Proceedings of Sorghum in the Eighties will be a prominent benchmark for our future studies and perspectives on sorghum in the next decade.

L.D. Swindale
Director General

Session 6

Production Technology

Chairman: R. Nicou
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Rapporteurs: M. R. Rao
Bhola Nath

Cropping Systems with Sorghum

R. W. Willey, M. R. Rao, M. S. Reddy, and M. Natarajan*

At its simplest, a cropping system can be a single crop, but most farmers grow more than one crop. In the developing tropics, for example, the farmer may have to grow several crops to satisfy different dietary requirements, to spread labor peaks, or to spread risks caused by the vagaries of weather, pest attack, or market fluctuations. Thus a cropping systems approach must recognize that the farmer often has to optimize returns from a combination of crops and that the overall productivity of the whole system is as important as the productivity of any individual crop.

A major factor determining overall productivity is the efficiency with which the cropping system uses the basic growth resources, especially those that are limiting. This will depend not only on the efficiency of the individual crops that make up the system but also on how well these crops complement each other in time and space. Thus specifically considering sorghum systems, overall productivity will depend partly on the efficiency of the sorghum crop itself and partly on how well sorghum fits in with other crops.

It is not within the scope of this paper to discuss the efficiency of the sorghum crop in any detail, but it is worth noting that compared with many other crops sorghum is inherently very efficient. It emerges quickly and produces a relatively rapid ground cover, is efficient at using limited amounts of water and nutrients, and has a C_4 photosynthetic pathway and a high crop growth rate. This is illustrated by some dry-matter accumulation and light interception patterns of sorghum compared with groundnut and pigeonpea (Fig. 1).

This high efficiency of the sorghum crop suggests that complementary resource use between sorghum and other crops is most likely to occur in those systems where the peak growing periods of sorghum and the other crops do not coincide. Clearly, such temporal differences are achieved where the other crops are grown as quite separate ones either before or after sorghum. As will be seen later, these systems can be very productive and a major factor contributing to their success is the availability of short season sorghum genotypes; in fact, from the cropping systems viewpoint the importance of these genotypes lies not so much in their higher yield potential as in the increased time and opportunity they provide for other crops. But temporal effects can also be achieved in intercropping systems where there is at least some temporal displacement between sorghum and its associated crops, and such systems will be discussed in some detail. It will also be seen that even where temporal differences do not occur, there are some intercropping systems where sorghum is able to complement other crops to achieve better spatial use of resources.

Types of Cropping System

The cropping systems considered in this paper are briefly defined here and are then discussed in the following sections.

Intercropping

This can be defined as the growing of two or more crops on the same piece of land at the same time. The sowing or harvesting times of the crops can differ, but their growing periods overlap. The essential characteristic of this system compared with the systems listed below is that there is competition between the crops.

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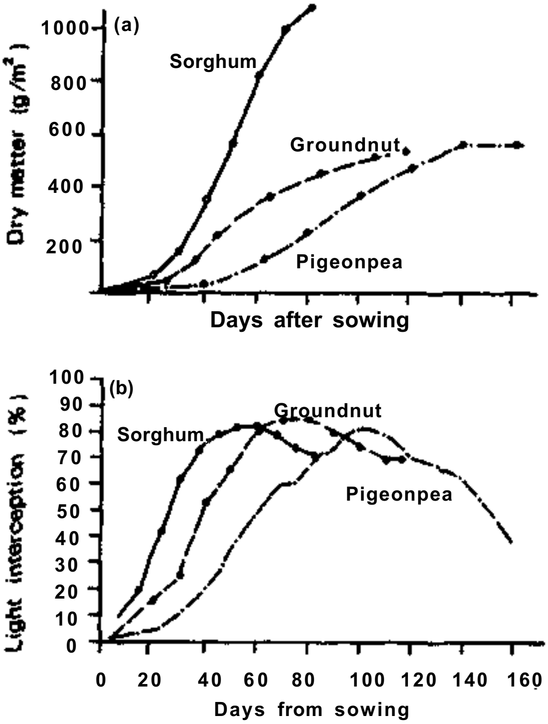

Figure 1. Dry-matter production (a) and light interception (b) by pigeonpea, sorghum, and groundnut as a function of days from sowing.

Sequential Cropping

This is a sequence of sole crops where one crop is sown after the harvest of a previous crop. It is usually understood to be a sequence within one cropping year. The terms "double-cropping" and "triple-cropping" are often used to denote sequences of two and three crops, respectively, in the same year.

Relay Cropping

This is where a second crop is sown into a standing first crop shortly before harvest. The system is distinguishable from intercropping because the period of overlap (usually 2-3 weeks) is too short for the occurrence of any significant intercrop competition.

Ratoon Cropping

This is where a second crop is grown by cultivating the regenerating stubble of a first crop.

Rotational Cropping

This refers to cycles of crops over a number of years.

Intercropping

The efficiency of intercropping systems are most often assessed in terms of their land equivalent ratio (LER) which is defined as the relative land area that would be required as sole crops to produce the yields achieved in intercropping. Though defined in terms of land area, this also indicates the relative yield advantage of intercropping; thus an LER value of 1.20 indicates that intercropping outyields sole cropping by 20%. It must be appreciated, however, that this indicates the relative increase in yield achieved by intercropping compared with growing the same component crops at the same time but separately. While this may be the comparison most often required, it can sometimes be desirable in the broader cropping systems context to compare intercropping with different crops and different systems. Examples where this is appropriate will be given later.

One of the major reasons for higher yields from intercropping is that the component crops are able to complement each other and make better overall use of resources when growing together than when growing separately. As emphasized earlier, the greatest scope tor complementary effects is usually when there are temporal differences between the crops and thus it is largely on the basis of broad temporal categories that the different intercropping systems are considered below.

Intercropping with Long-season Sorghum

With the long-season, photosensitive sorghums, temporal complementarity between crops is often exploited by growing them with an earlier maturing intercrop. A well documented example of this is the millet/sorghum combination of N. Nigeria where it is estimated to occupy 18% of the mixed crop area (Norman 1972). Generally, millet is sown at the very beginning of the rains and sorghum is sown a little later. In experiments at Samaru, Andrews (1972) showed that this system could give yield advantages of 50% (i.e., LERs of 1.50) and up to 75% greater monetary returns than sole sorghum. If a row arrangement of 1 sorghum: 2 millet were adopted, a reasonable crop of cowpea could be grown after the millet and between the rows of sorghum, and monetary advantages could be increased to 89% more than the sole sorghum. In a later study, Andrews (1974) showed that it was also possible to introduce an improved dwarf sorghum into this system and so gain the benefits of higher sorghum yields.

Baker (1979a) reported further work on this system and emphasized the need for high populations of each component crop. In fact, high optimum populations have often been suggested for intercropping combinations with large temporal differences between crops; in effect the early maturing crop requires a high population to make efficient use of early resources, and the later maturing crop requires a high population to make efficient use of later resources. Baker also highlighted a further feature of these systems which is that total resource use may be further improved by including yet a third crop of complementary growth pattern. Thus Baker showed that total productivity could be increased by including a maize crop that matured after the millet but before the sorghum, though there was some sacrifice in sorghum yield.

In Central America, an early maturing maize crop is commonly grown with long season sorghums; Anderson and Williams (1954) described this system in Honduras and House and Guiragossian (1978) reported its prevalence in Guatemala, Honduras, El Salvador, and parts of Mexico. In these areas, rainfall varies between 1000 and 2000 *mm,* falling between May and October, but there is a distinct bimodal distribution with little or no rainfall in August. The crops may be sown together but more commonly the maize is sown at the onset of the rains and the sorghum is sown 3-4 weeks later. In some areas an intercrop of beans may also be added. Maize matures in August or September and the tops are then broken over to await drying and harvesting in November. Sorghum is harvested in December. The importance of the sorghum in this system lies in the fact that, despite the high average rainfall, there is considerable risk of drought because of the variability of the rainfall, the steep slopes, and the poor moisture-holding capacity of the soils. In good years maize is used for the family and sorghum for poultry, but in bad years, when the maize fails, sorghum is used as human food. In addition to this stability aspect, substantial yield advantages over sole cropping have been reported and breeding efforts are currently directed to improving sorghum specifically for this system (Clara 1980).

A combination of maize and beans is also used for intercropping in long-season sorghum in the highlands of Ethiopia (Gebrekidan 1977) where rainfall ranges from 800 to 1000 mm in a bimodal pattern. Sowing is done about April, in the short rains. Maize is harvested early for green cobs and fodder, followed by beans at the beginning of the long rains; sorghum is harvested in December after the long rains. No yield details for this three-crop system have been reported, though Gebrekidan (1977) has shown advantages for a two-crop system of beans with sorghum.

Many other crops have been reported as intercrops with the long season sorghums, e.g., chat *(Catha edulis)* and sweet potato in Ethiopia (Gebrekidan 1977), benniseed, roselle, groundnut, and niger in Nigeria (Yayok 1981; Baker 1978), and cowpeas in many West African countries (Stoop 1981). Two of the West African systems illustrate, first, the wide range of objectives that the farmer may have in terms of the proportion of sorghum he requires and, second, how significant yield improvement can be achieved without jeopardizing these objectives. In the sorghum/groundnut system the farmer sows predominantly a groundnut crop with only a very sparse stand of sorghum. Clearly in this situation the valuable groundnut crop is the important component of the system, but Baker (1978) has shown that worthwhile increases in sorghum yield can still be achieved without significantly sacrificing groundnut. In contrast, the cowpea/sorghum system is usually a full stand of sorghum with only occasional plants of cowpea. In this situation the staple cereal is the vital component but again it has been shown that cowpea yield can be usefully increased without sacrificing the cereal (Serafini, personal communication).

Intercropping with Short-Season Sorghum

With Later-maturing Crops

With the short season sorghums, large temporal differences between the component crops are achieved by using the sorghum as the earlier maturing crop. This situation is typified by the sorghum/pigeonpea combination that is particularly important in India and also occurs in East Africa. In both these areas the sorghum is usually regarded as the main component; in fact in India, the traditional objective is to produce a "full" yield of sorghum with some "additional" yield of pigeonpea. The farmer achieves this by sowing several rows of sorghum and only occasional rows of pigeonpea. While this safeguards the sorghum yield, however, it severely limits the pigeonpea contribution and thus yield advantages are low.

Figure 2 shows the growth patterns of an improved sorghum/pigeonpea situation where the pigeonpea was sown in every third row but the population of each crop was maintained at its full sole crop level by reducing within-row spacings. The dry matter accumulation of intercropped sorghum was only slightly less than sole sorghum and grain yields were similar at 4240 and 4500 kg/ha, respectively. Thus, despite the high sown proportion of pigeonpea, an almost full yield of sorghum was achieved by maintaining the full sorghum population.

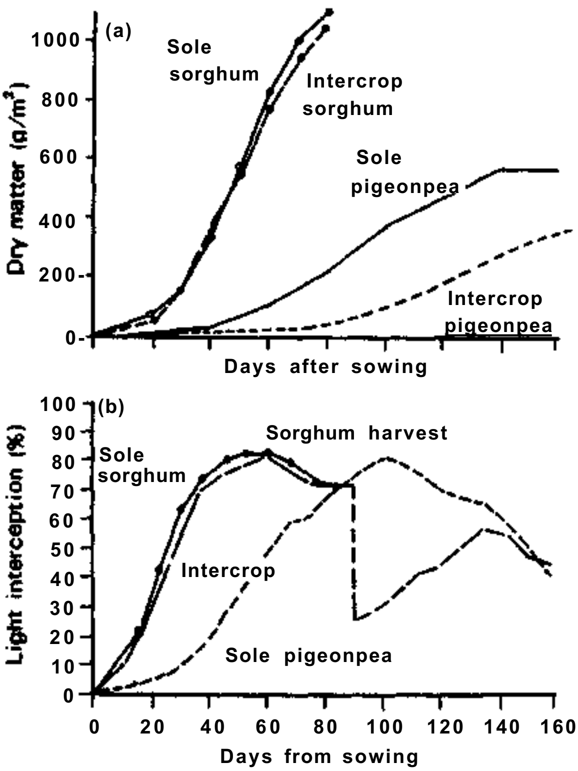

Figure 2. Ia) Dry-matter production by sorghum and pigeonpea in sole and intercrop systems as a function of days from sowing; Ib) light interception by sole pigeonpea, sole sorghum, and combined intercrop as a function of days from sowing.

Figure 2 also shows that although the pigeonpea component suffered considerable competition during the period of sorghum growth, it partially compensated later and was finally able to produce a dry matter yield equivalent to 53% of the sole crop. Moreover, because the sorghum competition largely suppressed the early vegetative growth of the pigeonpea, the harvest index was increased from 22% in sole cropping to 30% in intercropping; thus the intercropped pigeonpea seed yield was a very considerable 72% of the sole crop.

It must be emphasized, however, that these particular figures were obtained from deep Vertisols which have a very high moisture holding capacity and which in the Hyderabad situation have a potential growing period of about 6 months: In this situation it is important to compare the intercropping system with other possible systems such as sequential or relay systems, and such comparisons will be made in a later section. On lighter soils, however, there is usualy little or no opportunity for sequential or relay cropping and although intercropped pigeonpea yields are usually less (40-50% of sole crop yields on Alfisols at ICRISAT), in these situations the yield advantages indicated for intercropping (e.g., by the LER) are genuine yield increases over sole cropping.

Sorghum is also found intercropped with other long-season crops. In Maharashtra state in India a typical traditional pattern is several rows of cotton with a strip of two to three rows of sorghum and pigeonpea, either in separate rows or mixed within the row. With the introduction of improved genotypes of cotton there has been a move to sole cropping though studies have still shown worthwhile advantage of intercropping. Thus with Lakshmi cotton and CSH-6 sorghum, Prithvi Raj et al. (1972) showed intercropping yield advantages of more than 30% for row arrangements of 2 sorghum:2 cotton or 3 sorghum:2 cotton; moreover both these intercrops gave higher monetary returns than either sole crop.

Sorghum is also one of the cereals intercropped with cotton in Nigeria, though the cotton cash crop usually suffers considerable competition, because it is relegated to much later planting than the staple cereal. Baker (1979b) has shown that if both crops are planted early, then profits can be increased. In Northeast Brazil, perennial cotton is invariably intercropped during its first year, usually with maize and cowpeas or beans. With the increasing interest in sorghum in this area, early studies have suggested that sorghum would be equally suited to this system (Lira et al., 1978).

From the nature of its growth pattern, castor would also seem to be a suitable intercrop with sorghum but the maximum advantage reported has been 27% (Rao and Willey 1980a) and several studies have shown less advantage (Freyman and Venkateswarlu 1977) or none at all (Reddy et al. 1965; Chowdhury 1981). These disappointing results seem to be because castor is very susceptible to competition from the sorghum and, unlike pigeonpea, it does not have the ability to compensate, especially in the new, short statured, earlier maturing genotypes. However, one recent study (Chinnappan and Palaniappan 1980) has shown substantial monetary advantages from a three-crop system of sorghum, castor and blackgram. Sorghum has also been tried with banana (Randhawa and Sharma 1972), sugarcane (Zende and Patil 1972) or cassava (KKU-Ford 1977) but in all these experiments sorghum was the subsidiary crop and results were considered disappointing because yield of the main crop was reduced.

With Crops of Similar Maturity

Intercrops with a maturity similar to sorghum include a range of low canopy legumes (soya, groundnut, *Phaseolus* beans, cowpea, or chickpea) and other cereals (maize, pearl millet, or setaria). With soya, many experiments have been carried out in India, where the emphasis has usually been on the sorghum. A summary of a set of 18 of these (Rao and Willey 1979) reported yield advantages of 22% (96% sorghum and 26% soya) from a 2 sorghum: 1 soya row arrangement, and 25% (89% sorghum and 36% soya) from alternate rows. Other workers have reported advantages of the same order, or even higher (Bunpromma and Mabbayad 1978—23%; De and Singh 1981—36%; Singh 1977—43%). In the USA, Wahua and Miller (1978) reported advantages of only 8% and 11 % when a soya intercrop was grown with a dwarf or tall sorghum genotype, respectively.

Sorghum/groundnut research has again been concentrated largely in India. Early experiments examined low proportions of sorghum to maintain high groundnut yields and yield advantages were relatively small (John et al. 1943; Bodade 1964; Lingegowda et al. 1972). More recent experiments have included high proportions of sorghum and advantages have been as high, or even higher, than with soya (Singh 1977—48%; Tarhalkar and Rao 1981—57%; Rao and Willey 1980a—38%). Some of the earliest intercropping studies in Africa (Evans 1960) also examined quite high proportions of sorghum and showed very large advantages up to 61%.

In Northeast Brazil, *Phaseolus* beans and cowpea are commonly grown with maize, and recent studies have examined these two legumes with sorghum. Yield advantages have been quite promising (20-25%—Mafra et al. 1981) and current evidence suggests that, from the point of view of crop complementarity, sorghum will prove to be as suitable as maize in these systems.

Sorghum/chickpea, grown as a postmonsoon crop in several ICRISAT experiments, has given only moderate yield advantages of 15-20%. One particularly interesting feature of these experiments, however, has been the evidence of a beneficial shading effect on the chickpea, in agreement with studies carried out by the pulse physiologists using artificial shades.

Combinations of sorghum with other cereals of similar maturity can be quite commonly seen in farming practice but these situations have attracted little serious study. Early ICRISAT experiments (Rao and Willey 1980a) reported advantages of 29%, 18%, and 18% for maize, pearl millet, and setaria, respectively, when grown in alternate rows with sorghum, but Haizel and Twumasi-Afriyie (1977) found no advantage in a sorghum/maize combination in Ghana. More recently, studies at ICRISAT have examined sorghum/pearl millet combinations with a range of genotypes of each crop. Though yield advantages of more than 30% have been recorded, these effects have still been largely ascribable to maturity differences, despite the fact that these have been very small (a maximum of 3 weeks). However, there was some evidence that height differences may have contributed to a small extent.

To summarize these combinations with crops of similar maturity to the sorghum the quite large yield advantages with many of the combinations indicates the possible importance of spatial complementarity in intercropping. In particular, the large advantages with some of the legumes (notably soya and groundnut) compared with the small advantages with other cereals emphasizes the benefits that might accrue due to major morphological or physiological differences between the crops. Unfortunately few of the sorghum/legume experiments reported have been sufficiently detailed to indicate how such yield advantages may occur, but some useful pointers can perhaps be gained from recent detailed studies with pearl millet/groundnut.

In an experiment with 1 row millet:3 rows groundnut, a yield advantage of 26% was obtained (Reddy and Willey 1981). Measurement of resource use showed some evidence of more efficient water use, both in terms of a greater total extraction from the profile and in terms of a greater proportion of water passing through the crop rather than being lost by evaporation. Nutrient uptake was also greater, the increase being proportional to the increased yield; however, though it was useful to note that this greater uptake could occur, it was not possible to determine whether this was a cause or an effect of higher yields. But the most striking effect was an increase of 26% in the efficiency with which intercepted light was converted into dry matter, probably because of a complementary effect between the C_4 millet and the C_3 groundnut. It seems likely that most of these effects could equally well occur with sorghum systems.

A further possible cause of yield advantage in these sorghum/legume mixtures could be a beneficial nitrogen effect from the legume, but the authors consider this unlikely. This effect is extremely difficult to determine in the field, but even claims of such an effect are exceptions rather than the rule. Moreover, cooperative studies with the ICRISAT microbiologists on groundnut intercropped with sorghum, maize, or pearl millet have shown that even where groundnut growth has not been affected, the nodulation and fixation have been much reduced, probably because of shading.

With Earlier-maturing Crops

Even with the short-season sorghums, some of the very early legumes can provide an intercrop that will mature a few weeks earlier. Such combinations might well benefit from some temporal complementarity as well as the possible spatial complementarity discussed above. With mungbean, which usually matures in 65-70 days, a review (Rao and Willey 1979) of 12 experiments conducted in India reported yield advantages of 31% (100% sorghum and 31% mung) in a 2 sorghum: 1 mung arrangement and 34% (95% sorghum and 39% mung) in an alternate row arrangement. May and Misagu (1980) also reported very good mung yields (93% in 1 year and 86% in another, averaged over 20 genotypes) but they did not report sorghum yields. With cowpea, six Indian experiments (AICSIP 1981) showed similar overall advantages (34%) to those with mung, though the cowpea proved to be slightly more competitive (87% sorghum and 47% cowpea). Studies in East Africa with a *Phaseolus* bean maturing about 1 month earlier than the sorghum showed advantages up to 55% (Osiru and Willey 1972).

Some other Aspects of Intercropping

It is often suggested that intercropping gives better control of weeds, pests or diseases. Considering the weed control situation first, there is good evidence that this can be improved where the intercrop situation provides a community of plants that are in total more competitive than the individual crops. Thus Rao and Shetty (1976) showed that the high populations required to give maximum yield in sorghum/pigeonpea also gave advantages of greater weed suppression. It has also been emphasized that these higher populations and the associated improvement in ground cover can give better weed control in other combinations (Okigbo 1981).

But with pests and diseases the situation is much more complex. Detailed ICRISAT studies in sorghum/pigeonpea have shown that the presence of sorghum increases the incidence of *Heliothis* pod borer on the pigeonpea, but it can markedly reduce pigeonpea wilt disease. It is also well known that in West Africa sorghum (or other cereals) can reduce the thrip incidence on intercropped cowpea. These examples illustrate that intercropping with sorghum can produce both beneficial and adverse effects on pests and diseases; and while these may be associated with cereals in general rather than sorghum in particular, they are none the less important.

Because of the poor conditions under which sorghum is often grown, a particularly relevant aspect of intercropping is that relative advantages may often be greater under low fertility and/or low moisture situations (Rego 1981; Chowdhury and Misagu 1981; IRRI 1975; Reddy and Willey 1980; Natarajan and Willey 1980; Oelsligle et al. 1975). This is undoubtedly one of the mechanisms that could result in the greater yield stability that is often claimed for intercropping and that has been emphasized for maize/sorghum in Central America (Anderson and Williams 1954) and the long season sorghum systems of West Africa (Norman 1972; Baker 1978). Recently, a detailed study (Rao and Willey 1980b) has been carried out on 94 sorghum/pigeonpea experiments in India, ranging from rainfall regimes of 408-1156 mm and across sole crop yield levels of 310-6200 kg/ha for sorghum and 274-2840 kg/ha for pigeonpea. If crop "failure" is measured as monetary returns falling below a given "disaster" level, then for an example disaster level of Rs.1000/ha, sole sorghum fails 1 year in 8, sole pigeonpea 1 year in 5, but the intercrop only 1 year in 36.

Sequential Systems

Sequential cropping requires a relatively long growing period and in the rainfed semi-arid tropics it is not usually possible in the areas with lighter soils and/or low rainfall. Thus on the Alfisols of India it is only viable on the deeper soils with high rainfall, and even then it is probably limited to hardy "catch" crops grown after a rainy-season sorghum (AICRPDA 1976). But in more favorable situations, such as the deep Vertisols, there are many reports of short season sorghum crops being successfully followed by a wide range of second crops (Rao 1975; AICRPDA 1980; Reddy and Willey, in press). Studies over a number of years at ICRISAT have indicated that productivity can be 40-100% greater than traditional single crop systems. However, although this degree of increased productivity is extremely attractive, there can be considerable practical problems for the farmer, mainly because of the higher inputs of fertilizers, sprays, labor, and managerial skill required. In particular, the success of the system very often depends on a rapid turnaround between the two crops to ensure adequate moisture for establishment and subsequent growth of the second crop; but this period is also a very critical labor peak for harvesting and threshing the first crop. To facilitate this turnaround it would seem worth considering the minimum tillage systems that have proved possible with sequential sorghum systems in developed areas (Nelson et al. 1977; Camper et al. 1972).

Sequential systems based on a rainy season sorghum crop also raise the dilemma of what the optimum growing period of the sorghum should be; earlier maturity increases the likelihood of good moisture conditions for the second crop but it increases the problems from head molds or wet harvesting conditions. This is the kind of cropping system decision that the authors are currently trying to elucidate (in conjunction with ICRISAT agroclimatologists) by fitting a water balance model (Reddy, in press) to long-term rainfall data. Table 1 gives the example of an Indian location, Indore, which has 1000 mm of rainfall and which is on deep Vertisols with a moisture storage capacity of 250 mm. After a 105-day sorghum crop, the probability of having sufficient stored moisture and rainfall for a second crop is only 51 % of the years. But, almost half of these years will have insufficient showers for ensuring that the top 2-3 inches of soil are wet enough for germination. Thus despite the apparently favorable rainfall and soil situation, the probability of double cropping at Indore with a 105-day sorghum as the first crop is only 27% of the years. However, if the sorghum growing period is reduced by 2 weeks to 91 days, the probability is substantially increased to 60%. At the same time the probability of having wet conditions at harvest is only increased from 24 to 30%. As a first approximation, therefore, the analysis suggests an overall advantage for a sorghum of less than 105 days for this particular location. But the moisture criteria tentatively used in the model still need further consideration and refinement before reliable conclusions can be drawn. On the whole, however, the approach would seem to have potential.

The above analysis also raises an important point of comparison between these sequential systems and a sorghum/pigeonpea intercrop. In the latter system the pigeonpea effectively acts as a second crop but the difficulties of having to establish a crop after sorghum harvest are avoided. Not surprisingly, therefore, where there are risks associated with establishing a second crop, the intercrop is usually a better alternative and is certainly much more stable; in fact in the Indore example the probability of success for the intercrop is 97%.

Table 1. Probability of success of different cropping systems at Indore, India, calculated from 37 years' rainfall data using a water balance model (Reddy, in press). This location has an average annual rainfall of 1000 mm and is on deep Vertisols with a moisture-storage capacity of 250 mm.

	First crop		Second crop (or pigeonpea intercrop)		
	Sufficient moisture for growth (%)	Wet week at harvest (>50 mm) (%)	Sufficient moisture for growth (>200 mm) (%)	Insufficient rain for establishment (<20 mm), even though sufficient for growth (%)	Total probability of success (%)
Sequential system (first crop 105-day sorghum)	100	24	51	24	27
Sequential system (first crop 91-day sorghum)	100	30	73	13	60
Relay system (first crop 105-day sorghum, overlap 14 days)	100	24	73	13	60
Sorghum /pigeonpea intercrop (sorghum 105 days, pigeonpea 180 days)	100	24	97		97

Other sequential systems have sorghum as the second crop. For example, in those deep Vertisol areas of India where sorghum traditionally follows a rainy season fallow, there can be opportunities for adding a rainy season crop (Reddy and Willey, in press). In many areas there is also increasing interest in sorghum as a crop after paddy rice (Hooper et al. 1975; Samphantharak and Sriwatanapongse 1977; Salahuddin 1977). Indeed, where irrigation is possible, sorghum is a component of a wide range of double and triple crop systems (Leeuwrik and Mahapatra 1970; Naidu 1971; Hukkeri et al. 1978; Garrity et al. 1979).

Relay Systems

The overlapping of crops by relay cropping ensure that the second crop is established before the critical labor peak for harvesting the first crop. It shortens the total growing period and can be especially appropriate where the available growing period is just too short for a sequential system. It can also provide the advantages of an earlier sown second crop without the disadvantages of an earlier maturing first crop. For example, in the Indore situation described above, a relay system where a second crop was sown 2 weeks before the harvest of the 105-day sorghum crop would give the same increased chance of success as the sequential system based on the 91-day sorghum crop; it would not, however, incur the additional harvesting problems associated with the 91-day crop. Successful relay systems have been reported where horsegram or pigeonpea have been the relay crops after sorghum (AICRPDA 1978), and where sorghum itself has been the relay crop after maize (ICRISAT 1980).

Unfortunately, relay cropping can be a difficult system to operate in farming practice. It can be difficult for the farmer to sow the relay crop into the standing first crop unless hand sowing is being practiced, and there is also a danger of damaging the seedlings of the relay crop when harvesting the first crop.

Ratoon Systems

The importance of ratoon cropping has been reported in a number of countries (USA—Plucknett et al. 1970; Worker 1961; Australia—Parberry 1966; India—Ambastha and Jha 1955; Mandal et al. 1965). Much has been written on the practical management of ratoon crops but this paper will deal only with cropping systems implications.

Considering first of all the system of two consecutive grain crops (i.e., a "plant" crop and a "ratoon" crop), the major advantage of ratooning is that it avoids having to sow the second crop. This saves on the cost of cultivations and seed, it reduces labor demands at a critical postharvesting period, and in the rainfed situation it avoids the risks associated with sowing the second crop. Because the ratoon crop gets a particularly rapid start and also matures earlier than a normal plant crop, the system also has the advantage of a shorter total growing period requirement.

The disadvantage of this system, however, is that the ratoon crop usually produces a lower yield than a sown crop. At ICRISAT, recent studies under favorable moisture conditions and over a wide range of genotypes have given ratoon yields of about 50-65% of the plant crops. Thus on yield considerations alone, the ratoon system is unlikely to compete where good sequential or relay systems are viable alternatives. In the rainfed situation its niche is probably the production of a low cost "partial" second crop where moisture conditions are insufficient for a full second crop.

But sorghum's ability to ratoon allows the possibility of a wide range of other systems where one or more of the crops are taken for fodder. In India, systems have been described where an irrigated fodder crop has been grown in the summer season and followed by a ratoon grain crop during the rains; compared with a normal rainy season crop, the earlier maturing ratoon crop gives a greater opportunity for traditional postrainy season crops of cotton (Mandal et al. 1965; Shanmugasundaram et al. 1967) or wheat (Pal and Kaushik 1969). A rather different system is where a rainy season plant crop is cut for early fodder (about 45-50 days) which then has the effect of delaying the maturity of a ratoon grain crop until the drier conditions after the end of the rains (Sanghi and Rao 1976). The danger of shoot fly attack is probably the greatest drawback to these fodder/grain systems.

Where irrigation is possible, systems with two or three consecutive ratoon crops have been described (Plucknett et al. 1970; Hussaini and Rao 1966; Rojas 1976).

Rotational Systems

Many of the general principles of rotations, such as the maintenance of fertility or the control of soil-borne pests and diseases, are no more applicable to sorghum than to other crops and this will not be dealt with here; neither will the special problem of *Striga* since this is being covered elsewhere in this symposium. But one aspect not covered elsewhere is the depressive effect that sorghum may have on the yields of following crops.

Some commonly suggested causes of this depressive effect are the depletion of nutrients and moisture, and the locking up of available nitrogen by microbial action in breaking down the carbon-rich stubble. But while there is good evidence that these factors are often involved, there are instances where fertilizers and irrigation have not eliminated the effect. The suggestion of toxic exudates from the sorghum stubble has always had a mixed reception among scientists, though recent work has shown very convincing evidence of excessive production of phenolic acid that can certainly affect crop growth (Ganry 1979, personal communication).

But whatever the cause of the effect it has been reported with a frequency difficult to ignore; it has been reported in USA, India and Africa, and on a very wide range of crops (sorghum itself, wheat, oats, barley, cotton, chickpea, pigeonpea. and groundnuts). Its effect seems to be greater on cereals compared with legumes. Thus poorer wheat yields have been reported after sorghum than after maize (Myers and Hallsted 1942; Dunkle and Atkins 1944; Quinby et al. 1958; Singh and Singh 1966; Laws and Simpson 1959). especially where wheat has been sown immediately after the sorghum rather than in the following year (Myers and Hallsted 1942). or where rainfall has been low (Laws and Simpson 1959). Lower cotton yields have been reported after sorghum compared with pearl millet in South India (Ayyar and Sundaram 1941), or compared with fallow or lobia in the Sudan (Burhan and Mansi 1967; Roy and Kardofani 1961). Recent ICRISAT studies on pigeonpea, chickpea or sorghum grown after maize compared with sorghum showed very drastic reductions of 49-87% in 1 year (which the authors consider must have involved some phytotoxic effect) but only moderate reductions of 10-15% in another 2 years (Fig. 3).

Further work on this subject would seem to be desirable. In the meantime it should be recognized that in some cropping systems the net contribution of the sorghum crop may not be as high as its own yield indicates because of lower yields in subsequent crops.

Genotypes for Specific Cropping Systems

It is often stated that genotypes should be selected specifically for the systems in which they are to be grown. While this is no doubt true, it does not necessarily mean that different systems have very different genotype requirements. Some systems may have little in the way of special requirements beyond the need for an appropriate maturity period, and this presents no particular conceptual or technical difficulties. But the notable exception to this is the intercropping system where genotype selection must recognize that genotypes will ultimately be grown in competition with another crop. For this system much more consideration needs to be given to the identification of desirable plant characters and the formulation of appropriate screening procedures.

Unfortunately, intercropping systems are almost infinitely variable, and the sorghum genotype required is likely to vary according to the nature of the associated crop and the exact way the crops are combined. This can be illustrated with reference to two types of intercropping systems. The first is where the sorghum is grown as a very high proportion of the system and it is the dominant crop. This is typified by the sorgum/pigeonpea combination in which, as seen earlier, the sorghum is grown at its full sole crop population and the objective is to produce at least 90-95% of a sole crop yield. In this system, it is particularly easy to predict how a given sorghum genotype will behave since it virtually behaves as a sole crop. Moreover, because of the dominance of the sorghum, it is not difficult to predict that pigeonpea yield will be increased as height and/or maturity of the sorghum is decreased, and this has been verified in field studies. Thus this system represents one of the simpler situations where the desired plant characters, the sorghum intercrop performance, and the performance of

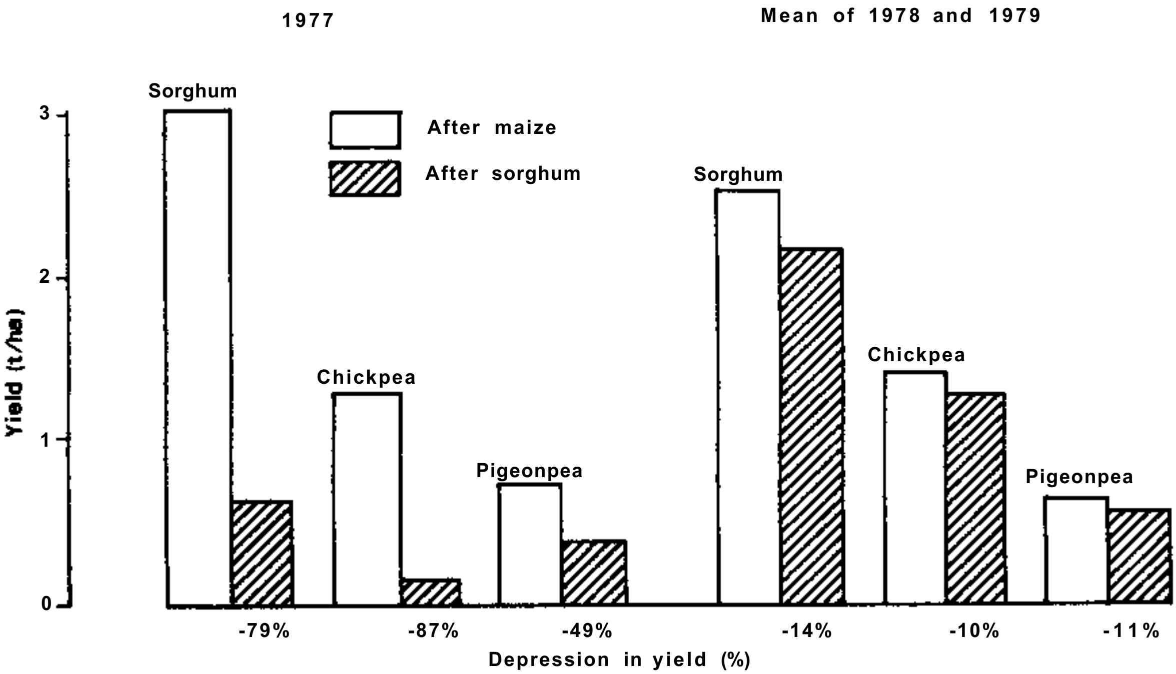

Figure 3. Yield of postrainy-season crops after a rainy-season crop of maize or sorghum (ICRISAT data).

the associated crop can all be defined at least in broad terms. It can be argued, therefore, that this system presents few special problems and there may even be little need for selecting within the intercropping situation itself, except perhaps in the final stages of evaluation.

The other type of system is where sorghum is grown as a smaller proportion of the system and there is much more of a two-way competitive interaction between the crops. This is exemplified by a sorghum/cowpea combination currently being examined at ICRISAT, and in which the arrangement is a simple proportional one of 1 row sorghum:2 rows cowpea in 45 cm rows. In this situation the sorghum behavior is usually quite different from that in sole cropping in that it responds to its lower population by increasing yield per plant; ideally this response should produce the appropriate balance of competition and some degree of complementarity with the cowpea. At the present state of intercropping knowledge these effects are extremely difficult to predict. Thus it seems inescapable that if breeders seriously wish to produce sorghum genotypes suitable for this type of system, some screening will have to be done in the intercropping situation itself. This can require considerable resources, especially when interactions with different genotypes of the associated crop have also to be taken into account. A possible approach, which applies both to sorghum and its associated crop, is that in the early stages of selection, when genotype numbers are high, screening could be done against a standard genotype of the other crop. When a few of the more promising genotypes of each crop have been identified, these can then be examined in combination.

A further feature of interest in the ICRISAT sorghum/cowpea studies is the attempt to identify the importance of individual plant characters. This is being done by examining a large number of sister lines that differ in such characters as height, maturity, or canopy structure, but which otherwise have a relatively homogenous genetic background. It is hoped that this will allow the effects of each character to be isolated from the confounding effects of other characters.

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Crop Management

M. D. Clegg*

The general methodologies of crop management, as currently carried out in the various countries of the world, are extremely variable. This is because there are many environments with farm sizes ranging from less than 0.5 hectare (Harwood and Price 1976) to farm sizes that are in excess of 1000 hectares (Schertz 1979). Regardless of farm size, the goals of farmers are to produce maximum crop yields by managing the farming system so that environmental stresses are minimal to the growing crop.

According to Zandstra (1977), yield is a function (f) of management (M) and environment (E):

$$\bar{y} = f(\bar{M}, \hat{E})$$

The symbol M includes the consideration of the choice of variety, the procedure of plant establishment, arrangement in time and space, fertilization, pest control (weeds, insects, and disease) and harvesting. The symbol E includes the land (soil characteristics), climate variables (rainfall, daylength, solar radiation, and temperature) and economic resources (power, labor and cash). Throughout this symposium most, if not all, of these variables will be addressed.

Because crop management encompasses these many variables this paper will be directed to various cultural practices or considerations which have developed in the last decade. Furthermore, it will be necessary to discuss practices peculiar to both large farms (high mechanization) and small farms (little mechanization). In many cases the principle of the cultural practice will apply to either.

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Present Considerations

Large Farms

The number of crops grown on large farms are few. In many instances only one crop is grown because of the characteristics of the environments. This results in highly specialized farming.

Variety Selection

New high-yielding hybrids are continuously being released by commercial seed companies. Resistance to insects and diseases, seed quality, as well as climatic stresses are considered in the development of the new hybrids. Farmers choose hybrids which are adapted to their areas from these companies.

Seed of hybrids sold to farmers is processed to insure a high quality product. Processing includes sizing, fungicide treating and packaging. Because seed size varies considerably, the number of seeds per bag are indicated allowing the farmers to plant the correct amount of seed per unit area.

A recent innovation is to protect the seedlings from herbicide damage by the application of a chemical protectant, which allows the use of higher concentrations of herbicides for weed control with less risk of seedling injury (Bumside et al. 1971; Spontanski and Burnside 1973; Ellis et al. 1980; Nyffeler et al. 1980; Henken 1981).

Plant Arrangement

Variability of plant height, leaf direction, leaf number and leaf size exists in grain sorghum. Proper spatial arrangement is needed for each genotype in an environment to balance the radiation load for maximized yields and efficient water use. With irrigation or favorable environments, maximum radiation can be intercepted for

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru, A.P., India. Patancheru, A.P. India: ICRISAT.

utilization because water is available for continuous transpiration and minimal heat and water stress. Interception of radiation can be increased with narrow rows and high plant populations (Clegg 1971). This is a practice which is used to obtain a more equidistant plant arrangement in order to optimize water use (Richie and Burnett 1971; Blum and Naveh 1976; Meyers and Foale 1981). As conditions become more arid, the radiation load is reduced by lowering plant population and widening rows, and by using a more rectangular plant arrangement, to optimize more efficient water use (Blum and Naveh 1976; Meyer and Foale 1981).

The greatest problem with narrow rows is that mechanical cultivation is difficult and weeds need to be controlled early. However, adequate weed control can be obtained using herbicides (Burnside 1977).

Surface Mulch

Reduced tillage systems which leave residues on the soil surface are gaining favor because of better moisture conservation, improvement of soil physical properties, and soil erosion control. These systems also reduce tillage time and minimize a delay in planting due to inclement weather (Lane and Gaddis 1976).

In the more arid areas, ecofallow and no-till fallow are becoming popular (Greb and Zimdahl 1980; Peterson and Fenster, in press). These systems depend on contact and preemergence herbicides to control summer weeds. With ecofallow, some tillage is required for late summer weed control and reduction of residues to facilitate planting (Peterson and Fenster, in press). Benefits of these systems are many. Loss of soil by wind and water erosion is reduced (Lane and Gaddis 1976; Good and Smika 1978; Peterson and Fenster, in press). Increased water infiltration, and reduced evaporation thereby, results in increased water storage. Further, increased moisture occurs in environments where winter snow is common. The residue allows for increased snow catchment and the stubble allows for more efficient snowmelt storage (Nordquist and Wicks 1976; Good and Smika 1978; Peterson and Fenster, in press). In environments which are marginal for continuous cropping, a wheat-maize or sorghum-fallow-wheat cropping sequence was successful as compared with the conventional sequence of wheat-fallow-wheat-fallow. This was because enough moisture was stored using these no-till or limited-till systems (Nordquist and Wicks 1976).

There are several problems inherent with leaving residues on the soil surface. The greatest problem is the need for special planting equipment (Peterson and Fenster 1981). Soil temperatures are reduced (Nordquist and Wicks 1976; Lal 1978; Unger 1978) with a temperature difference of 5.5°C (Good and Smika 1978). This lowering of temperature delays the time for soil to reach favorable temperatures for seed germination (Unger 1978) and requires earlier maturing varieties or hybrids since planting may be delayed (Nordquist and Wicks 1976). Herbicides used for weed control may result in carryover problems (Peterson and Fenster, in press).

Biological Nitrogen

Fertilizer, especially nitrogen which is required in large amounts, has been readily available in the past at economical costs. Nitrogen costs have increased considerably resulting in the consideration of using cropping systems which include biological fixed nitrogen. Maize realized approximately 90 kg/ha nitrogen following soybeans in a maize-soybean rotation (Shrader et al. 1966). Sorghum grown continuously over a 4-year period with no applied nitrogen yielded an average of 4600 kg/ha as compared with a sorghum yield of 6551 kg/ha when grown in rotation with soybeans with no applied nitrogen. The yield level attained by sorghum in the rotation system was equivalent to 76 kg/ha applied nitrogen (Clegg 1981). This would indicate that a significant amount of biologically fixed nitrogen can be obtained from cropping systems. Other benefits of changing crops are that they aid in controlling insect pests and diseases, and with soybeans the fields are in excellent condition for a no-tillage operation.

Mechanization

The labor requirement and the number of farm workers have declined in the Great Plains of the USA as a result of fewer but larger farms and the development of larger tractors and machinery (Lagrone 1979). A farmer can easily till or plant 100 ha per day.

Irrigation has developed on marginal land with leveling and the use of center pivot irrigation systems. Maize has generally been grown on developed lands because of its response to irrigation. However, increased irrigation has resulted in the lowering of the water table. This will result in the near future in acreages being shifted back to dryland farming (Lagrone 1979).

Small Farms

Numerous crops may be involved with small farms. In a study by Norman et al. (1979), the cropping area included 29 crops of which 60% were cereals (sorghum and millet), 24% grain legumes, and 6% other crops. This resulted in 230 different crop mixtures excluding planting patterns and population densities. Sixty-two Bangladesh farmers used three cropping systems consisting of one, two, or three crops per year with different combinations of crop varieties for 19 different cropping patterns (Hoque and Rahman 1981). Thus, small farm agriculture can be very complex.

Variety Selection

The majority of small farms are in the developing countries. Because of limited resources, farmers select and harvest seed from their fields which are either local varieties or higher yielding improved varieties. Thus, most developing country programs are involved with variety development (Patanothai 1975). In Egypt, a high-yielding improved variety, Gizza 114, is predominantly grown by the farmers. A new improved variety, Gizza 15, is being introduced. They have a continuing maintenance and development of varieties as well as hybrids in their program. They also maintain foundation and registered seed of the improved varieties (Anon. 1981c).

Plant Arrangement

The general principles governing plant arrangement for small farms are similar to those for large farms, i.e., balancing the radiation load for maximized yields and efficient water use. However, with small farming the use of numerous crops in different combinations allows not only for spatial arrangement but arrangement in time. Intercropping, mixed cropping, relay cropping, sequential cropping and rotations are all systems which allow for plant arrangement in space and time.

Great interest has been directed towards these systems. Several symposia have dealt with the various aspects of multiple cropping (Multiple Cropping, 1976, ASA No 27; Cropping Systems Research and Development for the Asian Rice Farmer. 1977, IRRI; Cropping Systems Conference, 1980, IRRI). Allen et al. (1976) and Trenbath (1976) presented basic information needed for the cultural systems and Linger and Stewart (1976) provided information and materials for production.

Although there is much interest in developing new cropping systems, generally there is not enough thought directed to management. Sorghum schemes in Southeast Asia failed because harvest operations occurred during a period with expected rainfall of 25 mm per week (Harwood 1977). Failure of improved cotton over traditional cotton occurred because the improved cotton required more labor, and its culture conflicted with the weeding of their food crops (Norman 1980).

The greatest advantage of indigenous systems is that they are well adapted and require a low level of management (Krantz and Dart 1977). However, a study by CIMMYT of the acceptance of new technology where new technology had been introduced for at least 5 years showed adoption existed and decisions could be explained by the biological and economic circumstances of the farmers (Anon. 1981a).

Biological Nitrogen

Unavailability of nitrogen, a major plant nutrient, becomes a major constraint for good crop production in developing countries because of the general lack of economic resources. Legume crops are traditionally used in many cropping systems for their nitrogen fixation benefits or through the sparing effect on the availability of nitrogen for the associated crop in the crop mixture (Krantz and Dart 1977). Many studies show combined yield advantages of mixed cereal-grain legume cropping systems (Vorasoot et al. 1975; Wahua and Miller 1978; Natarajan and Willey 1980a, b; Mohta and De 1980). Wahua and Miller (1978) could show no evidence that sorghum actually gained nitrogen from the associated soybean crop.

Other benefits of cereal-grain legume systems are the reduction of insects and diseases, and furnishing a protein source for human nutrition.

Mechanization

There is a high labor requirement for small farms

(Neweke 1980). Periods which require intense labor (planting, harvesting) often cause labor shortages and result in reduced crop yields. Therefore, adequate planting and harvesting machinery for the Asian rice farmer are being developed (Anon. 1981b).

Developing machinery for many cropping systems is not difficult. Some modification of existing machinery will suffice. The difficulty arises when mechanizing the operations of mixed cropping systems which traditionally have depended on the use of hand tools (Erbach and Lovely 1976).

The economics of buying machinery is a serious constraint. In many cases, the cost of a machine is not in proportion to its size. A small tractor has essentially the same building requirements as a larger tractor.

Mechanization can result in unemployment (Erbach and Lovely 1976) and can cause serious problems. However, studies comparing animal-powered farming with tractor-powered farming showed that although the mechanized farm had a lower total labor requirement the amount of hired labor was greater than the traditional farm (Anon. 1981b).

Future Considerations

There are many opportunities for improving crop production and management. Variety and hybrid improvement with respect to general adaptation, grain quality, insect and disease resistance will always be a major objective. This is probably a technological improvement which is most readily accepted by farmers. However, there are areas which require specific adaptation. Certain soils are either deficient in certain minerals or have toxic levels. Brown and Jones (1977) have been able to obtain plants which grow well on soils deficient in iron, zinc and copper or at toxic levels of aluminum and manganese. The possibility of selecting nitrogen efficient genotypes exist (Maranville et al. 1980). Stress tolerances to high and low temperatures as well as drought are necessary.

Water is a resource which is becoming scarce in many areas because of well-irrigation reducing the water table at a higher rate than the normal recharge. Maize is usually grown because of its responses to irrigation, but the development of sorghums with high yields with limited irrigation could result in stabilization of water for these areas.

Minimum tillage systems retain considerable amounts of residue on the surface resulting in insulation and reduced soil temperatures at normal planting periods. This is especially serious in northern temperate areas. Selection of genotypes with cool tolerance for germination and emergence is needed (Nordquist and Wicks 1976). Minimum tillage for water conservation, erosion control and improved soil characteristics should be considered for some arid lesser developed countries. Similarly with the introduction of any new cropping system, a definite procedure for testing and selecting adapted genotypes is needed. In many cases, unique cultural procedures should be adopted in a breeding program. For example, the Egyptian farmers begin to harvest the lower leaves of sorghum and maize for forage soon after anthesis. This can continue until only a few leaves remain. This operation could easily be adopted in a breeding program for selection of improved varieties.

Biological fixed nitrogen may be one of the more productive areas for research. Traditionally, cereal-legume cropping systems have been used for the nitrogen fixing benefit of the legume. However, the exact mechanism involved for the cereal crop response is not known. Research should be directed to understanding this response. There are also associative nitrogen fixing systems which are unique to grasses (Dobereiner and Day 1975; and Singh et al. 1980) which should be explored fully.

Mechanization of crop production operations is necessary when labor becomes limiting or expensive. To mechanize requires capital and larger farming units which are usually main constraints in developing countries. Development of improved mechanized systems to reduce labor requirements and accelerate cultural operations seems plausible in place of a machine for every farmer. As an example, the Egyptian farmer harvests and bundles wheat by hand and then transports the bundles to a central area for threshing with a small engine powered thresher. The grain is then cleaned by winnowing. This harvesting operation could be improved by modifying a small readily available forage cutter for harvesting. A custom or cooperative combine could be used as a stationary machine for threshing and cleaning the wheat in one operation. The combine could easily be moved from one farmer's field to another. This system will also allow shortening the time between harvest and the next crop. A similar harvesting system could be used with sorghum and maize.

In conclusion, the complete management of all the farming operations must be considered when introducing new technology. Acceptance by the farmer will occur more readily if two conditions are met. First, the improvement does not greatly change the overall management of his farm operation and secondly, if a great change in management is needed because of the improvement, the improvement must contribute very significantly to increased crop production. We as researchers, spend full time on maybe one part of a systems operation and then expect a farmer to adopt the operation into his complete operation. The farmer ultimately decides what to adopt (Norman and Palmer-Jones 1977) and being human, most will not eagerly accept a piece of equipment, a procedure or an operation which results in increased work.

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Sorghum Seed Production and Distribution

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Grain sorghum [*Sorghum bicolor,* (L) Moench] is a staple food of a large section of the population in India and Africa. It is also extensively grown in the United States, parts of Central and South America, China, Pakistan and to a lesser extent in South east Asia, the USSR, and Europe. Although India has the largest area in the world sown to sorghum, it ranks second to USA in production.

Sorghum is primarily used for human consumption in developing countries and for livestock feed in developed countries. As with consumption, the production techniques vary greatly.

Most farmers in developed countries are educated. They have acquired improved human skills and managerial abilities. They practice efficient scientific agriculture and possess means to acquire new technology quickly. They are cognizant of the fact that no agricultural practices can improve the crop beyond the limits set by the seed, hence they mostly use seeds of high yielding and adapted hybrids for planting.

To cater for the enormous seed needs of the farmer-consumers, a specialized industry largely operated by commercial firms has developed to produce, process and market hybrid sorghum seeds.

The developing countries can be grouped into two distinct seed categories. First, there are those where research has developed superior hybrids and/or improved varieties and the necessary infrastructure to systematically produce and distribute quality seeds although most farming is yet at subsistence level. Government departments and private seed companies through their extension agencies have convinced some of the farmers to plant improved seeds and use scientific cultivation technology. Thus the farmers have been benefited and there is a slow but steady switch-over to improved seeds. Second, in many developing countries, the farmers save their own seed for next year's planting. These farmers are mostly illiterate and slow to adopt new technology. The technical know-how and infrastructure to multiply hybrid seeds is nonexistent. Limited quantities of improved variety seed is multiplied by government agencies and distributed free or at highly subsidized prices.

A seed program capable of providing farmers with good quality seed is essential to a nation's agricultural development. To be effective, such a program must be carefully tuned to the nature of farming in the country. As complex multi-cropping and intercropping systems are introduced, reliable seed supplies become more important. Regular supplies of seed of new crops and improved varieties should flow to farmers through an ever enlarging pipeline. Further, if the seed program is to succeed, the seed must be consistently better than the seed produced by the farmers themselves.

The seed program is, therefore, to be organized with the objective of planning, producing and making available to the farmers adequate quantities of high quality, genetically stable and pure seed of improved and adapted varieties, free from seed-borne parasites, and at a reasonable price. Seed production is thus a specialized and exacting task requiring standard conditions and proper supervision at different stages of production.

The type of seed production program to be developed in a country depends mostly on the social, economic and political circumstances of the country. The type can be official, semiofficial, cooperative, private, or a combination of these.

In most advanced countries, the seed enterprises are in the private sector. Many seed companies, some even multi-national, compete with each other to produce and supply seeds mostly of sorghum hybrids or of improved varieties. Many have created strong research

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programs to evolve closed pedigree hybrids. All have developed trained manpower and have created infrastructure to produce, process and market their seeds. Emphasis is on producing good quality seeds. They also develop and supply applied cultivation technology most suited to exploit their hybrid's optimum genetic potential. Most farms on which the seed is produced are large, and production techniques are highly sophisticated and mechanized.

In developing countries, most seed programs are started with government participation and/or through technical assistance from international agencies. The Food and Agriculture Organization is providing technical and financial assistance to many seed programs in Asia, Africa, and Central and Latin America. USAID also collaborates in many developing countries through the International Agricultural Development Services based in New York and provides financial and technical aid. Most of these collaborations are with recipient governments and do not encourage development of a seed trade in the private sector.

Wherever feasible it is desirable that parallel development of seed trade both in government and private sector should be encouraged. A fair competition among them will ensure timely and adequate supply of quality seed to farmers. Development of the seed industry in India is an excellent example where governmental and private seed agencies compete with each other to meet the farmers' seed needs. In a short span of just 15 years, over 50% of the area sown to sorghum during the *kharif* season is planted with hybrid seeds. Another example is the development of the Kenya Seed Company. Started by a group of progressive farmers some 25 years ago to grow quality hybrid seeds for its own needs, the company now meets the total seed demands of most crops of the entire country. It also grows hybrid seeds of many crops under contract solely for export. Although the company's majority shares are now owned by the government, it is managed on a commercial basis by competent technically qualified personnel, with reasonable profit as its motto.

Seeds are multiplied on government, cooperative or private seed farms in most countries. Where land holdings are small, seed villages are developed. Viable seed units are created by encouraging small seed farmers to undertake multiplication of only one kind and variety. The seed farmers learn production techniques quickly. With proper advice and guidance, they can and do produce quality hybrid seeds. Cheap and abundant human and animal resources are mostly used in field and plant operations.

Infrastructure and Resources

Adequate infrastructure in terms of trained technical manpower, physical facilities and financial resources is necessary for successful sorghum seed production. The seed enterprise irrespective of whether it is in developed or developing countries, in the public or private sector needs senior technical managerial staff to plan production targets, arrange basic seed, identify suitable production areas, arrange field equipment, develop seed processing facilities, and impart seed production training. They are also responsible for developing a suitable package of practices such as the ideal time of planting, plant density (row and plant spacing), amount and time of weedicide, fertilizer, pesticide and water application, and for distinguishing morphological characteristics of varieties, or both parents in hybrids, to facilitate proper roguing and timely harvesting.

The objective is to realize maximum seed yield per hectare and to maintain high standards of genetic and physical purity. It is easier to adopt the above practices where the seed agency is producing seed on its own or leased farms because all the operations are conducted by its own trained technicians. But most of the seed the world over is produced under a full procurement contract system with progressive farmers. The field operations are thus the responsibility of the farmer-seed grower. He needs to be guided in seed production techniques. Trained supervisors, who advise the seed growers and imbibe in them the concept of quality and ensure that all field operations, particularly timely roguing, are performed, are an integral part of any seed program. Their responsibility increases when seed production is undertaken with subsistence level, uneducated farmers in developing countries.

The seed enterprise requires finance for physical facilities such as offices, land, equipment for field operations and processing facilities, for recurring costs such as salaries of the staff and expendables such as fertilizers, pesticides, and packing materials, and to pay the farmers the cost of seed procured from them. The actual investment will depend on the quantity and kind of seed to be produced and the nature of facilities that are developed. The capital investment is usually much higher in the market oriented economy because the shortage and high cost of human resources demand mechanization and automation. The finance may be received as a government grant, loan from institutions responsible for rural development and/or from commercial banks.

Research Responsibility

Agro-research scientists working in the universities, plant breeding stations and international research centers cooperate to maintain a continuous flow of superior hybrids and improved varieties to replace the existing ones. The superiority may be for yield, resistance to pests or diseases, ability to withstand environmental stress or any other trait of economic value. In advanced countries, many private seed enterprises have also created research facilities and thus share the responsibility to evolve better sorghum hybrids and varieties. They do not disclose their pedigree and thus enjoy a monopoly on the production and sale of their seed.

In most developing countries, the responsibility to develop, test and release superior hybrids or varieties is entirely that of national research institutes. International research organizations such as ICRISAT also supply improved variety/hybrid trials and assist developing countries to plant and identify superior adaptable types. These are of open pedigree and any agency in the public or private sector can produce their seeds.

Seed Classes—Their Maintenance and Increase

The objective of seed production is to build a strong chain of multiplication of the various seed classes. Three stages of multiplication recognized in seed certification are:

1. Breeder's seed
2. Basic (foundation) seed, and
3. Commercial (certified) seed.

Breeder's seed is the first multiplication stage after a new superior variety or hybrid has been officially released, notified and recommended for cultivation. The responsibility for the increase of this seed class is usually with the originating breeder or his station. If the variety/hybrid has been developed through the cooperative efforts of a national or international research project, the coordinator nominates the breeder or breeders who will be responsible for breeder seed multiplication and supply within each country. In case of a hybrid, the male sterile line (A line), the maintainer line (B line) and the restorer line (R line) comprise the breeder's seed.

Breeder's seed of maintainer line, restorer line and variety are multiplied in a small plot, either under complete isolation or by controlled pollination usually on a university or research farm. The male-sterile line is increased by planting in an isolated plot A and B lines in alternate sets of rows (frequently 4 : 2 or 6: 2 A and B lines respectively). Each plant is examined at the vegetative, flowering and seed ripening stages for trueness-to-type and seed-borne diseases. The breeder and his staff ensure that the seed meets the highest standards of genetic purity, as one off-type plant will give rise to hundreds of such plants in the subsequent multiplication stages. Maximum care is taken to avoid all chances of mechanical mixtures during harvesting, threshing, cleaning, grading, packing and labeling of this seed class.

The general standards and specific requirements of breeder's seed are frequently not stipulated by most official seed certification agencies in the world, possibly because the authority competent to label breeder's seed is the originating/nominated breeder himself and he is beyond the purview of the certification agency. However, the breeder's seed must be field tested before it is released as a source for basic seed multiplication. The field test may be jointly conducted by the breeder and the seed certification agency.

As a matter of policy and convenience, adequate quantities of breeder's seed to last for 3-4 years should be multiplied at one time. The extra seed can be retained as a buffer stock for any sudden rise in demand or increased projected requirements. It will also avoid errors that tend to arise with frequent handling. Variations which tend to develop from delayed segregation, mutation, outcrossing, genetic drift or selection bias of the breeder will also be minimized. A suitable cold storage facility should be created at the research station to store the planned carry-over stock.

Basic (foundation) seed is frequently produced from breeder's seed. It is not necessary that production of all basic seed be from breeder's seed. As long as trueness-to-type is maintained it can be produced from existing basic seed. Generally one would go back to breeder's seed after every 3 or 4 increases. Basic seed is multiplied at the university seed farms or at the research farms of seed companies under the supervision of trained seed specialists. This seed class is usually certified because it is used for the production of certified commercial seed. All basic seed lots should be field tested for genetic purity before sale. The multiplication of the basic seed class should not be restricted to governmental agencies only. Free competition in its multiplication between the public and private sector should be encouraged to ensure adequate and timely supplies of seed with desirable genetic purity. A planned carry-over to the extent of 50% of this seed class is essential to safeguard against future failures from natural calamities or adverse agroclimatic conditions. Suitable cold storage facilities should be provided at production centers for storing the basic seed.

In advanced countries the maintenance and increase of the breeder and basic seed of closed pedigree hybrids is usually the responsibility of the parent seed stock multiplication departments within the seed companies. These departments are manned by qualified breeders and seed specialists. Many organizations in advanced countries also have made a business of producing and selling basic seed primarily of open pedigree hybrids.

In order to have sufficient quantities for the production of commercial seed, it may sometimes become necessary to introduce another class between the basic and commercial seed multiplication stages, particularly when multiplying seeds of sorghum varieties. This is known as *registered* seed. This seed class is usually produced on government seed farms or by experienced seed growers contracted by public or private seed companies. The production is supervised by trained seed technologists.

Commercial (certified) seed is produced from basic (foundation or registered) seed. This is the seed sold to farmers to sow their crop. Commercial seed is referred to as certified seed if it is produced according to prescribed standards which ensure trueness-to-type, germination percentage and seed purity. Certification is usually a voluntary process and may not be used by experienced companies having careful control of their production. In such cases farmers purchase seed, paying more attention to brand name than to the certification tags.

In advanced countries, most of the commercial sorghum seed is grown by private seed companies. Either they lease the land of farmers and carry out all operations themselves or they enter into a preagreed procurement contract where the farmer is responsible for all the cultivation operations, and roguing is handled by the company's trained technicians. Most seed farms are large. Mechanization is convenient and economical, and the company has control over operations whic determine the genetic and physical quality of th seed.

In developing countries, the certified commercial seed is produced either on large government farms or under contract with numerous small but progressive farmers. All field operations on government farms are handled by the salaried staff. Since the element of incentive is usually lacking, many field operations are not completed on time, which not only reflect on seed yields but also on its genetic and physical quality. Since government seed multiplication programs usually enjoy hidden or direct subsidies, they are able to attract the farmers by selling their seed cheaper.

The farmers with small land holdings either form themselves into a seed cooperative or enter into a procurement contract with the public or private sector seed companies. The seed companies are usually better organized. They hire competent technical staff who are conversant with advanced production technology and thus help their seed farmers in harvesting high acre yield while maintaining the high standards of purity. They create strong seed promotion, marketing, and after sales service departments, and they provide efficient and quick after sale services. They establish their brand image and farmers prefer to buy their seeds.

Problems in Seed Production

After superior hybrids have been bred they are evaluated in yield trials and large-scale farmer field trials before release. Most of the seed produced at research centers for evaluation trials is through hand pollinations. A systematic study on the ease of production in farmers' fields under various agroclimatic conditions should be done before a hybrid is released for commercial planting; however, this is seldom done. It is left to the seed producing agencies to obtain information on (a) days to flowering of each parent to ensure synchronization in the seed field; (b) the photosensitivity and/or thermosensitivity of the two parents in various agroclimates. which may differentially influence the time to flower, and (c) the length of the period of receptivity of the female parent, and information on flower characteristics, such as, length of style (sometimes the pistil may not emerge from the floret hence very poor pollen receptivity).

There are genetic problems which a seed producer faces, e.g., the pollen parent may be a shy pollen producer; absence or poor development of female floral parts in some florets due to genetic reasons; large variation in seed size and germinating value of seed from the same panicle; and very poor keeping quality of seed.

These problems can be illustrated from experience in the production of sorghum seed in India. In order to successfully produce F1 seed, synchronization of flowering of both the seed and pollen parent is essential, i.e., the pollen should be available to fertilize the stigmas of the seed parent when they become receptive. The first sorghum hybrid released by the All India Coordinated Sorghum Improvement Project was CSH-1. The male and female parents of this hybrid have more or less the same maturity, the height of the two parents is also similar and seed production has been very successful. There were numerous problems in multiplication of seed of the second, third and fourth sorghum hybrids released. Although these hybrids possessed a high yield potential and better grain quality, they had to be discontinued because seed production was almost impossible. The male parent of CSH-2 was almost two feet shorter than the female parent, hence the pollen could not reach the stigmas of the seed parent. The style of the female parent of CSH-3 and CSH-4 would not come out of the florets resulting in very poor seed setting.

The fifth hybrid released, CSH-5, has a very high yield potential but its male parent flowers between 15-20 days earlier than the female parent thus necessitating staggered plantings. Furthermore, the panicle of the female parent is very large, causing variation in seed size and germinating capacity. Moreover, the seed of this hybrid deteriorates fast in storage. There is a problem of poor development or even absence of female floral parts in certain florets from the same panicle in the recently developed sorghum hybrid CSH-9.

Quality Control

Quality control, voluntary or compulsory, is an integral part of any seed program. Seed that is sold to the farmer consumer should conform to certain standards of genetic identity and purity, should be free from inert matter, obnoxious weeds and seed-borne diseases, should be of high germinating capacity and possess the ability to establish vigorous seedlings. Most of the agriculturally advanced countries have legislation governing quality of seed sold to farmers. Even in developing countries where a beginning in organized seed trade has been made and farmers depend on outside agencies for their seed supplies, seed legislation has been enacted to safeguard their interests. The law may provide for compulsory certification by a recognized agency and prohibit the sale of seed to farmers unless it conforms to certain minimum standards. It must be truthfully labeled, i.e., the seed should be sold in containers clearly declaring the name, kind and variety of seed, its purity, germination, and other crop seed, weed seed and inert matter percentages.

In most developing countries where the farmer-consumers are illiterate, compulsory certification of seeds may initially be necessary to maintain their quality. Seed certification is a specialized and responsible job. Most decisions affect someone. When seed is rejected, the seed grower is a heavy loser. If seed which does not conform to standards is certified, all buyers of that seed will suffer. Therefore, the certification requirements should be definite, adequate and realistic and they should be adhered to equitably and with firmness. This job becomes easier if the certification agency is independent from the agencies producing and selling seeds, and also from the agency enforcing the seed act.

Isolation Requirement

Isolation in terms of seed production refers to separation of the seed crop by a specified distance in all directions from all sources of potential contamination during the growing period of the crop, especially flowering. For want of pertinent research data, seed programs in most developing countries have arbitrarily adopted the isolation distances that are used by the developed countries. They should in fact be fixed for each region after a careful study of factors which contribute to contamination such as wind velocity and direction of wind at flowering, natural barriers, insect activity, size of seed field, pollen shedding capacity of the male parent, etc. There is a real need to conduct experiments and come to some definite conclusion for each seed class and for each climatic zone.

Roguing

Although it is expected that the basic seed lots supplied for certified commercial seed production are field tested for genetic purity, off-type plants do appear. They may be delayed segregates, outcrosses, mutant or volunteer plants. The originating breeders should describe in detail the distinguishing morphological characteristics of a newly released variety or parents in the case of a new hybrid. During the process of multiplication from breeders through commercial seed, they help producers and certification inspectors to identify and remove off-types and thus maintain genetic purity of the variety or hybrid. The seed producing agency specialists should train the seed farmers to identify and remove all off-type plants at the vegetative, flowering and seed ripening stages. Maintainer line plants from female parent rows should also be removed daily during flowering.

Seed Harvesting and Processing

The procedure for harvesting the seed parent is more or less the same for all seed classes. Harvesting should begin only after the final (preharvest) inspection has been undertaken to remove leftover off-type and diseased earheads. Although sorghum seed is highest in quality when it attains physiological maturity, i.e.. about 30% seed moisture, harvesting at this stage is possible only if the facilities for artificial drying and threshing are available. Seeds harvested at this stage have a better appearance, are vigorous, have greater resistance to mechanical injury during drying-processing, and give increased yields.

Harvesting can be done with a combine or by hand. In the case of varietal multiplication, combine harvesting and threshing can be fast and economical but is possible only on large-size plots and is usually recommended only for the commercial seed class. The combine should be thoroughly cleaned before use. In most developing countries, including India, harvesting is done by hand at about 15% seed moisture. Panicles are sun dried for 2-3 days and threshed under bullock or tractor wheels. This does reflect on the physical quality of the seed and reduces its germination and storability but these are the cheapest, most readily available and most widely used methods.

Regardless of the class of seed, specific procedures have to be followed when two parents are involved (multiplication of A-line or hybrid seed). The restorer or maintainer rows are harvested first, threshed, stored, or sold. The technical staff of the producing agency and/or seed certification agency inspect the field for lodged or broken male panicles or plants of diseased panicles in the female parent rows and then give permission to harvest the seed parent.

The breeder's seed should be threshed with a small-size seed thresher at 12% seed moisture. These threshers can be easily cleaned thus avoiding chances of mechanical mixtures. The breeder or his associate can also examine each head before putting it through the thresher. Since the breeder's seed will usually be multiplied once in 4 years, mechanical injury to seed, which can reduce viability and vigor in storage, should be avoided.

The threshing of basic seed should be done on medium-size, power-operated threshers. The identity of each lot should be separately maintained through proper labeling and the seed may be stored in bulk or in new gunny bags until further processing.

After harvest the seed contains various admixtures which have to be eliminated before sowing. The seed is cleaned and graded to remove inert matter, undersized, broken or shrivelled seed, treated with an insecticide to provide protection against stored grain pests and a fungicide to protect against soil fungi on planting, then weighed, bagged, and stored until sale.

Seed Distribution

The channels of seed distribution for a private seed company are often different than the ones available to the public or government-run company. The efforts of the former are directed to establishing its brand image—the brand being a guarantee of its quality. The seed company slowly enters into new areas, plants demonstration plots and organizes farmer field days. Farmers the world over are shrewd and the most effective way to convince them is by the factual field demonstration of the superiority of the new product against the variety or hybrid that they are already growing. Once convinced they usually stick to that brand and even convince their neighbors to use it. Thus a seed company creates a more or less permanent market.

For distribution of seed, the private seed companies use the following chain on a commission basis:

	Area
Distributor (wholesaler)	Usually a whole state or province or division.
Subdistributor	Usually a district.
Retailer	Usually a taluka or block or group of villages.
Farmer-dealer or farmer service center	Usually 1-3 villages.

The retailer collects indents from each of the farmer dealers and then passes them to the subdistributor who in turn pools his requirement and sends it to the distributor. The company usually gets indents from all its distributors well before the ensuing planting season. In many areas the company often sells seed direct to the farmers through its retail depots or in weekly village markets. Usually all village farmers frequently visit the village cigarette and soft drink vendors. The Kenya Seed Company has efficiently used them for retailing seed.

In those countries where the seed programs are totally managed by public agencies, the distribution is also mostly through established government channels, such as block extension centers or village cooperative societies. The extension staff is responsible for convincing farmers to use improved certified seed. Often seeds are "sold" free or at subsidized prices.

In the countries where both the public sector and private sector companies compete, the former usually enjoys the benefits of direct or hidden government subsidies. They have the additional advantage of the free use of available government distribution channels. Usually the private sector is more effective wherever free and fair competition is permitted to prevail. Since it relies heavily on its brand image, it ensures that the seed sold meets the highest standards of purity, it creates an efficient after sales service system and is able to attend quickly to all complaints and thus retain its clientele. Above all it delegates authority for spot decisions which often finalize the deals in their favor.

Training Needs

Training is an important part of every seed program. Planners, senior executive staff, supervisors or technicians working at any level in a seed program should be well trained to perform their job responsibilities efficiently. Further, they should keep abreast with new innovations in their field to enable them to continuously improve their performance.

The training needs of the market-oriented economy may be different from those of the subsistence level economy. Thus training programs should be developed to suit the practical needs of each country. While the training needs of the technicians may be met through short courses of 3-4 weeks duration, or through in-service training, the managerial and supervisory staff may need specialized comprehensive training of 2-4 months duration. Seminars or workshops of 4-6 days duration may be adequate for planners and senior executives.

Many international organizations have prepared excellent material for such training courses. FAO/SIDA and CIAT regularly organize training courses for the benefit of seed programs of the developing world. They have prepared excellent guidelines, slides, film strips, etc., to make training programs meaningful and effective.

The Mechanization of Millet and Sorghum Production in Southern Mali

Mamadou Ba, Dramane Zerbo and Tiecouradie Diarra*

The Malian economy, which is characterized by an itinerant agriculture and which is not well advanced, today involves more than 85% of the total population either directly or indirectly. It was not until 1928 that Sub-Saharian Africa received assistance and then it was only in Mali where the first attempts were made to introduce animal traction machinery. Shifting agriculture, a practice which exhausts soils and as a result needs large areas permitting a long fallow, is experiencing a real transformation today, because of animal traction equipment and techniques.

Description of Project Zone

Project Zone

The Project zone is called South Mali ("Mali Sud") (Fig. 1). It spreads over three administrative regions, between 14° north latitude and the Guinean, Ivory Coast and Upper Volta borders. The area is 96 000 sq. kilometers. This region represents 8% of Mali's territory and 33% of the area where rainfed agriculture is practiced.

The Population of South Mali (1.5 million inhabitants)

This represents one quarter of the country's population—96% are rural, the rest live in towns of average importance. There are about 140 000 families involved in farming, mainly coming from the following ethnic groups: Bambara, Bobo. Minianka in the north and northeast, Malinke in the south and southwest. One should note that there are a certain number of Fulani.

The Climate

The climate and soils of South Mali are appropriate for a variety of crops. The climate is sudano-sahelian in the north and sudano-guinean in the south. The average annual rainfall varies from 700 mm in the north to 1400 mm in the south and is concentrated in a rainy season from May to October. The temperature varies from 26° to 31°C. This climate is particularly suitable for growing cotton and food crops.

The soils are light, easy to work and are suitable for millet, sorghum, corn, peanuts, cowpea, cotton, etc.

The natural vegetation is that of the savanna where the principal species are: *Parkia biglobosa, Butyrospermum parkii. Acacia albida, Tamarindus indica,* and *Adansonia digitata.*

A Brief History of Agricultural Mechanization in Mali

In West Africa, the most mechanized farmers are to be found in Mali. Their equipment is made up almost exclusively of privately owned animal traction machinery.

Today, everywhere in our fields modern equipment and traditional tools such as the "daba" (hoe) coexist. Great efforts are made to tip the balance in favor of modern equipment.

Traditional Tools

The daba is still the best known and perhaps the most widely used farm tool. It exists in many forms, changing with regions and soil types.

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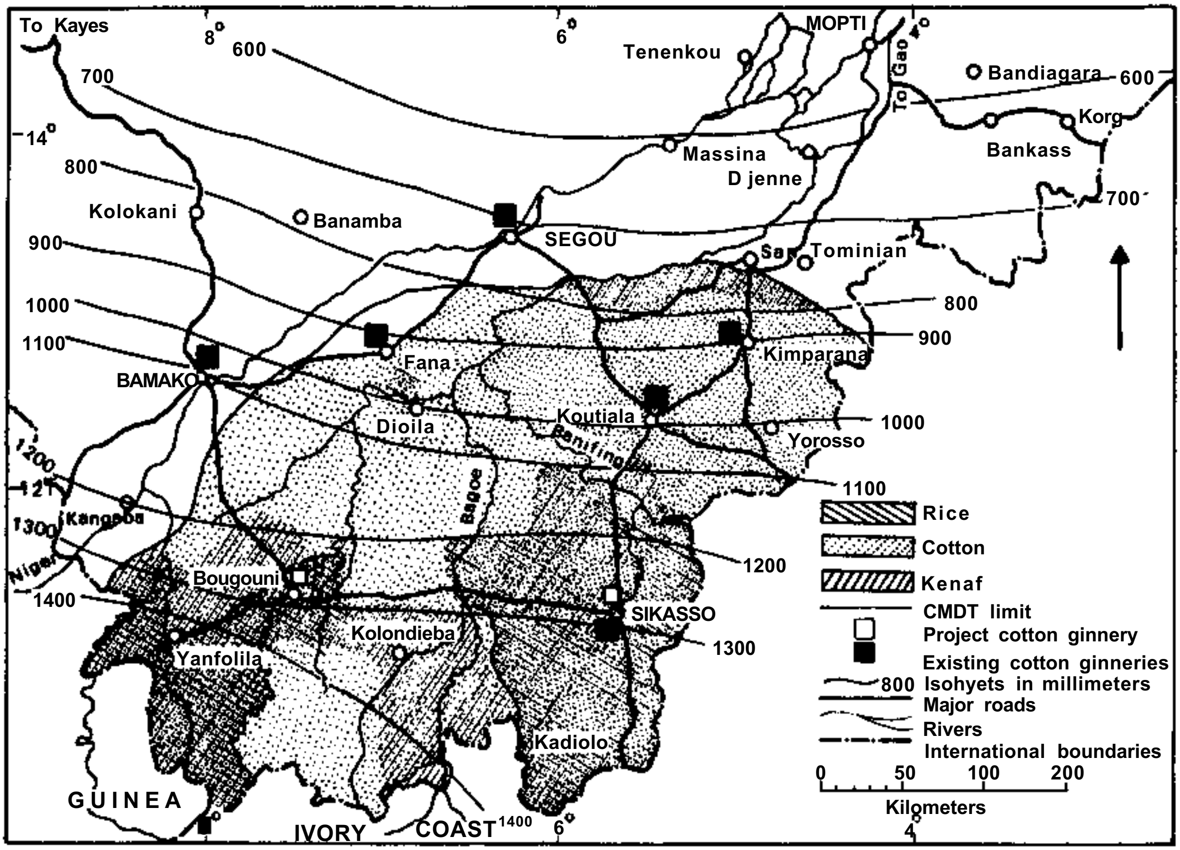

Figure 7. Mali Sud agricultural Project

In the area of Sikasso they work with a daba which has a large blade which is mounted obliquely on a short handle. In the rest of the zone, the blade is small to average size mounted on a long handle with the end curved for ease in handling when used. In the CMDT Zone 34% of the farmers have only this equipment while the situation in the whole country is 60%.

Traditional tools of local fabrication, often well adapted for their intended use, are of average quality and permit farmers to neither improve their traditional cultural practices nor to speed their execution.

The large-scale introduction of cash crops brought about a rapid reduction in the amount of time devoted to food crops.

Modern Equipment

Single row "light" mechanization with animal traction appeared in Mali in 1928. The General Directorate of Agriculture at that time through its three administrative centers, the Office du Niger, Baroueli, M'Pessoba with their master workers (farmers) whom they trained, began animal traction. The plow was the first piece of equipment introduced and the same type of plow can be seen today, La Bajac B2, and B4, in the rice-growing as well as the upland areas with the cotton and cereal crops.

The animal traction weeder came later and finally a complement of equipment for working the soil.

The Plow

Farmers in the CMDT zone are very fond of one type of plow—the Bajac TM (Tropical Mali). This plow weighs 34 kg and has a furrow slice of 11 inches (27.5 cm). It is generally pulled by one pair of bullocks, usually equipped with a neck yoke, but one sees some head yokes. This plow was originally made for a horse, but this animal is not used for agricultural activities (in Mali), and so it was soon used with a pair of bullocks. Despite the coming of the "Multiculteur" with its plow attachment, farmers still demand the "TM" plow which fills their needs very well.

At the same time, the early years of the introduction of animal traction techniques were very difficult, especially the introduction of plowing. In effect, flat plowing was often done by going around and around the field in such a way that when one arrives in the center of the field, foot traffic compacts the field and there is a large loss of time which results from the many turns and the increasingly short working distances. Thus, with the increased efficiency in mind many farmers directly plowed up ridges so that soil is placed on unworked ground which has negative effects on the plant development. While efforts have been made to correct this practice, it is still observed in certain parts of CMDT's zone of action.

The Star Cultivator

This is the most popular weeding tool. The standard model weighs 44 kg and has 5 cultivator shanks on which sweeps, scarifiers or ridgers are mounted. Rural craftsmen now fabricate many similar pieces of equipment which are very often quite light.

The "Multiculteur"

This equipment is light, weighs only 47 kg, and can carry out a variety of operations with various attachments such as a plow copied from the TM plow and weeding and ridging tools.

Farmers in the zone would willingly do without the "multiculteur" if they could be regularly supplied with the star cultivator at a reasonable price. Most often the "multiculteur" is used only for weeding and ridging. Many farmers do not use the plow.

The Seeder

This is a single row seeder with interchangeable seed plates, which can be used for cereals as well as for cotton and peanuts. This equipment has been extended only very recently. Users at this time wish that the tool could be made more versatile by mounting a fertilizer applicator.

The Cart

This piece of equipment has both agricultural and commercial uses and it is indispensable to our farms. Farmers carry manure, water, purchased inputs to the field, and their harvest to the village with it. It has many uses throughout the year.

After having tried different types of carts, metal wheels with and without a rubber covering, tires, metal and wood beds, with or without a traction bar, the cart with tires and an axle rated at 1 000 kg was found to be the best and is practically the only one in use today.

The Organization and Means of Activity

Mali Sud is an integrated development project which came about based on the experience of a certain number of other development programs. The CMDT* which was given responsibility for carrying out the project was created in 1975 to carry on the work of CFDT which had successfully developed cotton cropping in South Mali since 1952/53. As a rural development organization, the CMDT has been given the following activities:

- Increase the production of cotton fiber, jute, and cereal crops particularly millet, sorghum, corn, and rice by:
  - a. increasing the use of improved cultural methods,
  - b. increasing the area under cultivation.
- To put a viable extension service, and purchase credits for agricultural equipment and inputs at the disposition of the farmers in the area.
- Improve the methods of animal husbandry integrated in the farm enterprise.
- Develop the capacity to deliver primary health care.
- Assure the training and education of the rural population through literacy training for rural craftsmen and young farmers.

Important results have been achieved to date and have made agriculture in the zone much more "modern" than in the past. Traditional subsistence agriculture with elementary cultural techniques has become incapable of assuring a subsist-

* CMDT: The South Mali Project has been entrusted to the Compagnie Malienne pour le Developpement des Textiles.

ence for a normally expanding population while conserving the fertility level of the soil.

The Basic Extension Service

The basic organizational structure of the extension service has evolved little since it was restructured in 1960. In effect, it was at that time that the Malian Government, drawing from experience gained by the agricultural service over many years of evaluation marked by success and failure, decided to substitute a system of close supervision for the old system.

Up to that time, extension programs were carried out with a "spread supervision" system, that is to say, one supervising agent who was responsible for only one crop for 20 000-30 000 inhabitants.

- The "Zone d'Expansion Rurale" (ZER)
  With the new structure, the ZER became the organizational unit actually carrying out extension activities. It covered 15 000 to 20 000 inhabitants and it cannot cut across two administrative boundaries ("arrondissements"). The ZER, made up of many "base units" (Secteurs de Base, S.B.), administered by a technical agent who in addition to directing and controlling the activities at the S.B. level, plays the role of moral leader, seeing to it that the modernization efforts fit perfectly with the land and people.
- The Basic Units (S.B.)
  The S.B. is the basic unit for extension activities. The size can vary with local conditions but this is limited by the ability to have close contact between the extension agents and the farmers, and the necessity that this contact take place at the farm level. S.B.s normally have between 2000 and 3000 inhabitants representing 1000 to 1500 ha of cropped land.

Intervention Modes

To reach the project's objectives, modernization which will bring to the rural masses (populations) the possibility of social and economic development, must be realized.

For a long time the fundamental question of modernization in African agriculture was posed in terms of increasing only the productivity of the soil, that is to say yields/unit area. Animal traction was considered as an easy means to extend the cultivated area without increasing yields.

This perspective resulted from a sectorial view of things that would not be admissible today because diverse means and techniques are used in a necessarily interdependent way to improve the entire production system. As a result, the question is posed today in terms of raising productivity of diverse production factors (land, water, labor, and equipment). In many cases, most notably in the project zone, modernization of the farm enterprise brought about an increase in farmer income which in turn encouraged savings which favored further investment.

The necessity of relying on one cash crop to justify the effort was understood early and it was naturally cotton which was seen as the lever which the extension services needed to motivate this modernization. Cotton when grown with traditional methods only gives meager returns but it is very sensitive to improvements in cultural practices. It permitted farmers to equip themselves with farm machinery, animals, and undertake investments such as mineral fertilizers and phyto-sanitary treatments.

A farmer's efforts which favor his cotton field necessarily help his other crops: millet and sorghum which benefit from residual effects of fertilizers, plowing and weeding of cereal crop are carried out with animal traction equipment, etc. Thus, the farmer generally raises his productive potential and his resource base. A considerable extension effort was necessary to get the farmer started and to make him discontinue the traditional methods.

The conceptualization of extension themes took note of two essential facts:

(i) That it was necessary to respect a good balance of crops,

(ii) That it was necessary to respect the agricultural calendar.

A Good Balance of Crops

Mali has about 2 million ha where permanent rainfed agriculture is practiced on small holdings of less than 5 ha (1.8 million ha). About 90% of this area is in cereals and the rest in cash crops (cotton and peanuts). In the last few years, cash crop production, most notably cotton, has been increased considerably. Normal cereal production is estimated at 1.2 million tonnes per year while during the years of the great drought, 1972-74, the level was limited to 0.8 million tonnes. It should be understood that workers from the extended family cultivate at least one principal communal field and in addition there are many secondary fields of varying importance which have their own decision makers who are members of the extended family but function independently.

Taking into account actual levels of production, it has been noted that in order to conserve a production equilibrium, the farms in the project zone should respect a minimum ratio of 1 ha cotton to 3 ha of cereal, thus:

0.10 ha cotton/inhabitant
0.30 ha cereal/inhabitant.

The results of farm surveys conducted in the zone are shown in Table 1.

A reduction in cereal area/inhabitant could be due to the combined effects of a rapid increase in population and the drought which has been felt throughout the country. Nevertheless it can be seen from the table that there is a good relative balance of crops except around Koutiala where there is an important reduction in area cultivated in cereals. This may be explained by the high level of productivity in this region which has come about as a result of the use of proper cultural practices. The reduction in area around San is due to a restructuring of the zone; in fact the actual reduction is less than the table indicates.

The Agricultural Calendar (Tables 2 and 3)

The large-scale introduction of cash cropping and the increased demographic pressure have quickly brought about an important reduction in the area as well as the time that can be given to growing cereal crops.

The project zone is characterized by a single short rainy season which has been very irregular in the last few years, especially at the beginning. The season extends from the end of May to September. All rainfed crops must thus be grown during this period of about 4 months. Until recently millet and sorghum were planted with the first rains on unworked soil which the farmers would weed later so as not to lose time. Today, it has become imperative that millet and sorghum cropping be carried out with plowing or ridging to be successful even with early seeding.

These work times come from the IER (Institut d'Economie Rurale), April 1981, and represent 8 effective hours of work per man day or 10 hours of presence in the field which takes into account lost time for rest and meals. From the analysis of the two systems it is clear that the bottlenecks provoked either by increasing the area devoted to cash crops or the time invested in cereal production could not be overcome except by generalizing the use of animal traction. The gain of more than 6 man days during a relatively limited period of time, like the time of seeding, is considerable especially if one takes into account that animal traction results in better soil preparation, better root penetration due to improved tilth, incorporation of weeds and better soil aeration and a more active microflora.

The Evolution of Animal Traction Equipment in the Project Zone

The number of equipment units listed in Table 3 was used in 1979/80 to seed the following areas

Table 1. Area (ha) per inhabitant for cotton and cereals.

	Cotton		Cereals	
Regions	1969/70	1979/80	1969/70	1979/80
Fana	0.12	0.13	0.35	0.22
Bougouni	0.01	0.01	0.06	0.08
Sikasso	0.03	0.05	0.18	0.21
Koutiala	0.13	0.13	0.39	0.24
San	0.04	0.02	0.68	0.18
Segou	0.05	0.12	0.60	0.56
Average	0.06	0.07	0.37	0.25

with improved cropping practices:

Sorghum/millets	118 860 ha
Com	24 271 ha
Rice	4 604 ha
Jute	3 400 ha
Cotton	118 612 ha
Total	269 747 ha

The total available farm area in Mali is 6.72 million ha. Considering that most of the farmers who have a "Multiculteur" also have a plow, the following ratios are possible:

—Number of plow units
52 522 + 34 115 = 86 637

—Area tillable by these units if each plows 5 ha/unit: 86 637 x 5 - 433 185 ha.

—Number of units which may be placed:

$$\frac{6\ 720\ 000 - 433\ 185}{5} = 1\ 257\ 363$$

—Use efficiency of existing units

$$\frac{269\ 747}{433\ 185}\quad 0.62$$

The ratio of fields cropped with improved practices and the total number of farms (140 000) gives:

$$\frac{269\ 747}{140\ 000} = 1.926 \text{ ha/farm in improved practice}$$

This is far from the average levels desired by the project which previewed 5 ha in annual crops of which:

—Cotton : 1.0 ha.
—Cereals : 3.5 ha
—Others : 0.5 ha.

Equipment available per farm

$$\frac{86\ 637}{140\ 000} = 0.62 \text{ or } 1.6 \text{ farms/plow unit}$$

The potential area available for expansion would be:

$$\frac{6\ 72\ 000 - 433\ 185}{140\ 000} = 44.91 \text{ ha/farm}$$

Table 2. Comparative work time for traditional and animal traction with millet and sorghum.

	Number of days	
1. Traditional Cropping		
Clearing fields	12	
Seeding	2	
Thinning and transplanting	4	
Maintenance	18	
Harvest/threshing / winnowing/transport	25	
Total days/ha	61	
	Men	Equipment
II. Animal Traction		
Land preparation	4	2
Harrowing	2	1
Seeding	2	—
1st Weeding	5	1
2nd Weeding	5	1
Ridging	5	2
Harvest	10	—
Threshing/winnowing	15	—
Transport	2	1
Total days/ha	50	8

Observations

A summary of the lessons which may be drawn from this analysis:

- There is an enormous need for equipment.

Table 3. Number off farm implement units.

Implement	Before the project 1975/76	Project years 1976/77	1977/78	1978/79	1979/80
Plow	37 458	36 848	44 601	48 067	52 522
"Multiculteur"	20 247	23 726	28 560	31 355	34115
Cart	16 532	18004	22 041	24 524	25 412

- The under-utilization of certain equipment indicates that some farms are over-equipped.
- One equipment unit with a capacity of 5 ha takes care of more than two farms.
- The modernization effort needs to be continued and intensified so that the potential of animal traction may be exploited to its fullest.

Particular attention needs to be paid to those who receive equipment for the first time.

Techniques Realized with Millet and Sorghum

While no precise objective was set for the project, a particular emphasis was placed on cereal crops. The results in Table 4 show the development of production practices on these crops.

Area where techniques were followed should be understood to mean that the cereals were grown in rotation with cotton. The weeding bottleneck which could exist with increased area under cultivation as well as grouped early seeding was avoided with the use of animal traction equipment for weeding. The spread of animal traction is an indication of the progress in agricultural modernization.

The Socioeconomic Context of of Mechanization (Tables 5 and 6)

The agricultural modernization strategy in the project zone was originally based exclusively on placing imported equipment with a credit system which grew up over the years. At first the only efforts were directed towards cash sales through rural groups. Very early in the experiences volunteer farmers, chosen for their receptivity and discipline, began to receive interest-free credit for 2 years to purchase a pair of bullocks and farm equipment (plow, weeder, etc.) In return, the farmer committed himself to the program of the extension service. This system gave excellent results and permitted the project to rapidly pass on its techniqes to some farmers from whom the example spread readily.

The rhythm of equipment placement has been sensibly improved by the creation of a specialized credit service, initially with the Bank of Mali (1964-SCAER) and later a financially autonomous institution in 1971 (SCAER).

The purchase of equipment was made either through rural organizations or Rual Development Operations (CMDT) in the following forms:

(a) Cash payment funds received from the crop sales (cotton, cereals, animals).
(b) Money coming from commercial activities, a relative who is a bureaucrat, or a member of the family who is working away from the farm.
(c) Purchase on short-term credit.

The most common form, excluding timely monetary contributions by farm family members working temporarily or permanently in other sectors of the economy, was. and continues to be, medium-term credit. At this time this credit does not cover traction animals which must be purchased on a cash basis. The rest of the equipment was subsidized until 1976.

Because of the quality of statistics available, it is difficult to establish a clearly coherent link between the price of agricultural commodities produced with the equipment and the resulting production. Nevertheless, it can easily be seen that the purchasing power of farmers is being eroded.

Cash payment has become more and more difficult because of the deterioration in the sale terms. In effect, it can be seen in Tables 5 and 6 that 996 kg of millet or sorghum in 1977 was needed to purchase a plow; in 1980, at the official price, one needs 1 057 kg. This deterioration is more marked for the "multiculteur" whose purchase in 1976 required 1266 kg of millet or sorghum and today demands 1776 kg, thus 510 kg more in 5 years.

As a result of this reduced purchasing power, the following strategies permit farmers to fulfill their social and civic obligations:

(1) An increase in the rural exodus, both temporary and permanent.
(2) An increase of sales in the free market at more profitable prices.
(3) An extension of the area cultivated because of equipment loans to nonequipped farmers.

In effect, nonequipped farmers can nevertheless have access to equipment (plow, cart) on credit arrangements where the debt is repaid in kind, in cash, or with work during weeding or harvest. Naturally, the conditions governing the loan are defined as a function of the relationships between the parties as well as locally accepted practices.

Table 4. Changes in production and production practices (1975-1980).					
	Before the project	Project years			
	1975/76	1976/77	1977/78	1978/1979	1979/1980
Total area (est.) (ha)	430 000	420 000	450 000	450 000	450 000
Techniques followed (ha)	27 106	33 077	42 841	88 173	118 860
of which-plow	-	27 286	34 149	67 485	86 172
-seeded	-	5 791	8 692	20 688	32 688
-Seeded with seeder (ha)	-	4 989	9 324	21526	35 017
-Fert. 14N-22P-12K-85-2.5B (ha)	-	1 110	2 806	4 779	6 514
Weeded with "multiculteur" (ha)	36 964	33 449	40 414	70 257	83 569
-Ridged with "multiculteur" (ha)	27 961	11142	27 236	49 198	54 319
Average yield (est.) (kg/ha)	600	700	700	800	850

Table 5. Evolution of the cash prices (CFA) of the most important equipment (FM/unft).						
	Before the project	Project years				% increase
	1975/76	1976/77	1977/78	1978/79	1979/80	1980/76
Plow	31 860	45 650	47 880	52 870	52 870	166
"Multiculteur"	40 500	80 000	83 000	88 795	88 795	219
Seeder	24 975	55 500	55 500	58 010	58 010	232
Cart*	44 280	60 900	60 900	71 060	71 060	160

* For wheels and axle rated at 1000 kg; the frame and bed are manufactured by local craftsman.

Table 6. Evolution of crop prices (CFA/kg) to the farmer.						
						% increase
Products	1975/76	1976/77	1977/78	1978/79	1979/80	1980/76
Millet/sorghum	32	32	36	40	50	156
Paddy	40	40	45	50	62.5	156
Peanut	40	40	50	60	80	200
Cotton	75	75	90	90	110	147

Patterns in Agricultural Mechanization

Two clear patterns are observed. The first is observed with the majority of farmers, particularly those who own equipment for the first time. They want equipment which is increasingly specialized and light weight for many reasons, the most important of which are:

(1) The equipment in question is generally fabricated locally and the terms of payment are generally more reasonable.

(2) The limited capacity of their traction animals; weakened by their health, and the limited availability of forage in the dry

season makes these animals incapable of working more than a half day especially during the plowing period, the most critical time of the year.

(3) The equipment/teams are operated as independent units which increase the freedom of action by permitting different activities to be carried out at the same time.

The increase in the number of equipment types can be interpreted as an indication of the need for better adapted and performing equipment at a lower cost.

The second group are those for whom intermediate motorization addresses the profitability (production) limits of animal traction techniques. A simple motorized unit with versatile and dependable equipment which performs better than what has been used to date is needed. While the effort is in its 5th year, intermediate motorization is still in the testing phase. In effect, because of repeated failures with attempts at motorization, the project waited until 1977-78 to begin activities aimed at bringing about a successful effort of this type.

This activity, which today involves 79 exploitations in the Koutiala area, in the center of the project zone, is characterized by:

(a) sophisticated farmers
(b) animal traction since 1928
(c) logistic support that is available during all of the year
(d) large cultivated areas.

At the end of the 1981 /82 cropping season the agro-socioeconomic parameters of this system will be defined and above and beyond this we have a tractor and equipment which is viable from the point of view of operation and performance.

Future Orientations

The effort to transfer technology supposes that the conditions for its acceptance are at hand. These basic conditions relevant to agricultural mechanization can be summarized in three parts:

a. SELF-SUFFICIENCY. When the use of a piece of equipment or process becomes common; this is said to be the most important condition precedent on the farm. In effect, with our conditions, it is not enough to say that a new piece of equipment performs well or is profitable, but that it also must certainly be able to be, within the context in which it is used, supported by a large number of persons capable of providing necessary supplies and maintenance.

b. PERFORMANCE. The need for surplus production for security food stocks has made it necessary to put larger areas under production and it has as a result, become necessary to have more production per equipment unit to ensure adequate performance to guarantee that the production calendar is respected.

c. PROFITABILITY. NO less important than the other aspects and often in fact the limiting factor when one talks about important technological innovations which are available.

It follows that, one can foresee three steps towards increased mechanization in the project zone, i.e., light weight animal traction equipment; heavier animal traction equipment; and intermediate mechanization.

Light Weight Animal Traction Equipment

This step principally concerns those who are being equipped for the first time and this is the largest group. The equipment is based on the TM plow and the donkey cultivator; specialized equipment comes in a second phase which should be left to the initiative of the farmers.

The need must be recognized, in a more and more important way, to make the equipment lighter so that it can be used throughout the project zone. One notes a tendency towards cheaper traction animals, like the donkey, in place of bullocks or even the use of cows or a single bullock for work which does not demand a very high traction effort (especially seeding and weeding).

Our figures indicate that there are more farmers who purchase a second piece of equipment than those who purchase for the first time. This comes about because of the price and credit relationships. Improved credit is necessary for this type of peasant. Particular attention should be given to credit for traction animals, the biggest investment involved in the expansion of animal traction.

Heavier Animal Traction

The increase in the number of traction units in certain farms results in an over-equipment and there is nothing left but to look for a better performing equipment. The fact that there is not any "heavy type" (multiple row tool bar type) animal traction equipment available is aggravating the situation.

Less than aggressive trials of the "polyculture" have been made in the area but the farmers were able to see the price/benefit relationship. They were struck by its performance for seeding, weeding and ridging, but they were not similarly impressed by its ability to plow. The tractive force which it demands and the price made it unacceptable.

The petroleum crisis and worldwide inflation clearly pose the necessity to internalize the heavy animal traction phase. This equipment needs to be perfected because all that has been tried to date has not been satisfactory. We hope that over the next 4 years that some equipment distinguishes itself by its performance in trials off-station, with farmers.

ICRISAT/Mali, as part of its research program, has used a number of tool carriers which, when used with appropriate cultural methods, have shown themselves to be effective and can solve the problem of precision seeding and weeding.

Working on this basis, "Division du Machinisme Agricole" of Mali collaborating with an ICRISAT consultant has fabricated different tool carrier prototypes of the "Barre-Nolle" type. This tool carrier has variable wheel spacing from 120 to 180 cm and has been successfully used for seeding and weeding. It is also possible to work on ridges as well as on flat ground. Earlier, seeding and weeding on ridges was not possible with existing equipment. While it is well known that weeding is the limiting factor for total area cultivated, one should also note that existing equipment is not adequately utilized for these operations; weeding is therefore often done with the traditional daba.

While some farmers satisfactorily carry out interline weeding with the "multiculteur", this assumes that the precision of row spacing has been achieved either by using a seeding rope or precision seeding equipment.

In terms of work time, the seeding and weeding operations carried out with the tool carrier used are 2 to 3 times as fast as the "multiculteur" because they cover 2 to 3 times the surface with one pass in the field.

The existence today of a reserve of rural craftsmen trained and equipped and thus capable of bringing the logistic support necessary to animal traction makes it necessary to first exploit to the fullest the possibilities that this step brings before moving to intermediate mechanization.

Intermediate Motorization

While in the 5th year of experimentation, this phase is not well understood. It is focused on farms which have a great deal of experience with animal traction and which have substantial revenues, i.e., sufficient to make the investment.

Because of the training and necessary follow-through, farmers were chosen in an area relatively close to support the services around Koutiala, Fana and Sikasso and governed by the following strict criteria:

(a) 15-20 ha cultivated land plus available fallow.
(b) sufficient family workers (at least 8 active).
(c) the desire of the head of the family.
(d) proven debt worthiness.

A preliminary study permitted a choice of farms which have received a tractor and accompanying equipment on credit over 5 years with the 1 st year deferred but payment in cash thereafter. In addition, at the beginning of each cropping year a sum is paid in advance for the functioning of the machine (fuel, lubrication, spare parts, etc.). The farmer pays cash for repairs after the 2nd year. The 1st year is considered as a training and adapting period.

Three existing project sections today are responsible for: training tractor drivers, putting the equipment in place, supplying inputs, repair and maintenance, the control and supervision of the agronomic practices of the farmers, and the preparations and execution of a work plan with the agreement of the head of the farm.

Given the responsibility, which is difficult to pass on in the short term, especially if one knows the complexities of motorization, of never going beyond one day for repairing an equipment unit, the experience shows that there is room for improvement.

Conclusion

While the agricultural potential of the zone offers great potential, the farmers make less and less effort to equip themselves because of the price structure and the lack of adequate credit. Efforts must be undertaken with an emphasis on those who equip themselves for the first time otherwise we will assist in over-equipping those who were equipped while equipment was cheaper. This necessitates that one does not allow, to the degree that it is possible, the prestige that motorization brings within the village to bring into question the order of development steps. In other words, it would be desirable to exploit all of the potential of animal traction before going onto intermediate motorization.

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A Strategy to Raise the Productivity of Subsistence Farming Systems in the West African Semi-Arid Tropics

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Sorghum is the most important rainfed cereal crop in the West African Sudanian climatic zone, and it is a major crop in the Sahelian zone. Traditional varieties are generally tall and photoperiod-sensitive with maturity durations ranging from 160 days in the south (Sudanian zone) to 115 days or less in the north (Sahelian zone). Average grain yields under traditional management vary from 800 kg/ha in the south to 400 kg/ha in the north.

For Upper Volta some of the major factors underlying these low yields have been reported by Stoop and Pattanayak (1980). These factors include a low and unpredictable rainfall, poor soils with low available water-holding capacity, low moisture infiltration rates due to a crusting soil surface, and generally low fertility. Most traditional farming is based on hand labor, and complementary inputs are often unavailable or too expensive for small farmers.

Variation in rainfall patterns and soils in West Africa has led to a diversity in traditional farming systems. This diversity itself is probably one of the major reasons why sorghum improvement programs have not yet been successful in introducing improved varieties at the farmers' level despite nearly two decades of research efforts. This paper discusses the environmental factors, rainfall and soil, in the West African Sudanian zone, and to a lesser extent the Sahelian zone, and the traditional farming practices that have evolved in response to this environment. It critically discusses the approaches adopted in sorghum improvement work in West Africa during the past 20 years, and analyzes the impact of these programs on sorghum cropping in the region. Finally, this paper presents strategies for sorghum improvement and agronomic improvements that may have greater likelihood of success in the 1980s.

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The Physical Environment: its Effect on Cropping Patterns

The two major natural sources of variation within the semi-arid tropics (SAT) are rainfall—its total amount and distribution over the year—and soils. In the West African SAT, average rainfall decreases from south to north with isohyets more or less parallel to the equator. Some data on rainfall characteristics in Upper Volta are given in Table 1. Similar situations occur in the other West African countries of similar latitude. Within rainfall zones, various soil types occur, usually linked to a specific position in the topography. Shallow, gravelly soils are generally associated with upland areas, whereas deeper soils (sandy loams or silt loams) occur on the slopes, gradually changing to hydromorphic soils in the lowlands (Stoop and Pattanayak 1980). A considerable lateral water flow through the soil from upland areas is common and, as a result, the best agricultural land is most often found on the lower slopes bordering rainy-season swamps.

Some important differences exist between soils of the West African SAT and the Indian subcontinent (FAO/UNESCO 1974). The fertile alluvial soils and black clay soils (Vertisols) that are found in large areas in India are much less common in West Africa and tend to occur in isolated patches. Red soils, mostly Alfisols, that are common to both continents, appear in India to

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contain more clay and considerable amounts of illite and montmorillonite (Biswas et al. 1966; Kenchenna Gowda et al. 1966). In West Africa these soils are generally sandy with some kaolinitic clay. Analyses of samples of Kamboinse (Upper Volta) soil and Patancheru (India) soils are compared in Table 2. These data suggest differences in cation exchange capacity and exchangeable cations that make the Kamboinse soil less fertile and reduce its water-holding capacity (Table 3 and Moormann and van Wambeke 1978). Available soil moisture contents for many West African soils are in the range of 30-100 mm, while values of 150-300 mm have been reported for India (Virmani et al. 1978).

In West Africa, where soils generally have a low soil moisture content, farming is:

a. risky, since a drought period of more than 10 days during the cropping season can seriously damage the crop;
b. tied closely to the duration of the rainy season, the residual soil moisture being exhausted quickly thereafter. Unlike cropping practices in India, growing a postrainy season crop on residual moisture is rarely possible in most areas of the West African SAT, even on deep Vertisols.

Superimposed on these major variables of soils and rainfall one finds an array of farming systems adapted to local conditions, each with its own potential and constraints. West African farmers have adopted crops and cropping sytems that provide minimum risk while exploiting the entire duration of the rainy season. In the south, where the season is long, various cereal/cereal intercropping combinations are common. The actual system varies with soil type (Table 4) and often includes the combination of a short-duration photoperiod-insensitive cereal with a full-season photoperiod-sensitive cereal. Farther to the north, the rainy season is shorter and a single photoperiod-sensitive cereal (to allow planting with the first rains) is often mixed with cowpea as a minor crop. The choice of the dominant cereal, sorghum or millet, depends on the nature of the soil (Table 4). A further risk-reducing strategy by farmers is the reduction of plant populations in lower rainfall areas and on sandy soils. At first the multitude of

Table 1. Characterization of the rainfall pattern in three major ecological zones in Upper Volta.

Ecological zone	Mean annual rainfall (mm)	Approx. start of rainy season	Duration of rainy season (months)	Approx no. of rainy days	Peak rainfall months
South Sudanian Zone	> 1000	May	5 to 6	80 to 95	July. Aug. Sept
North Sudanian Zone	650-1000	June	4 to 5	60 to 70	July. Aug
Sahelian Zone	< 650	July	2.5 to 4.0	40 to 50	Aug

Table 2. A comparison of soil chemical properties between an Alfisol from Patancheru" (India) and one of Kamboinse (Upper Volta).

Location	Soil depth (cm)	pH	% Clay	CEC (meq/100 g soil)	Exch. cations Ca	Mg (meq/100g soil)	K
Patancheru (India)	0-18	6.7	29 6	10.0	6.7	1.5	0.7
	35-62	6.1	47.0	18.8	12.7	2.8	0.6
	62-105	6.4	55.2	19.8	14.3	2.7	0.8
Kamboinse (Upper Volta)	0-15	6.3	10.2	5.1	2.1	0.6	0.2
	45-55	6.4	26.3	6.6	2.9	1.0	0.2
	75-85	6.5	32.7	7.7	3.7	1.5	0.2

a. Data reported by Singh and Krantz (1976) systems observable may seem confusing; the variety, however, represents a logical response to environmental diversity. It is within this framework that one should examine the merits and weaknesses of local sorghums, and into which new varieties and technologies need to be fitted.

Given the uncertain rainfall, and low soil water-holding capacity, one can seriously question whether crop improvement programs based primarily on the same high-yielding variety (HYV) and input package strategies as used in the Indian environment can be equally effective in West Africa. Most HYVs require a high plant density in a pure stand to realize yield potential. This in turn requires a rather dependable soil moisture supply and high soil fertility.

Jha (1980) in a study of fertilizer use patterns in India arrived at conclusions on the use of improved varieties that have direct relevance to the West African situation. Fertilizer use was found to be largely explained by the size and certainty of returns that in turn were closely correlated with rainfall and irrigation density. This fertilizer use was greater in the irrigated and high rainfall districts and HYVs were also most common in these same areas. He concluded that, in SAT areas with high and more dependable rainfall or on soil with good moisture holding capacity, farmers will more readily adopt fertilizers and HWs than in areas with poor soils. Unfortunately poor soils and

Table 3. Available water-holding capacity in toils dominated by low (kaolinitic) and high (montmorillionitic) activity clays (after Moormann and van Wambeke 1978.)

Low-activity clays (CEC <24 meq/100 g clay)		High-activity clays (CEC >24 meq/100 g clay)	
Av. CEC (meq/100 g)	Av. AWC[a]	Av. CEC (meq/100 g)	Av. AWC[a]
14.6 ± 3.6	16.5 ± 6	62.8 ± 13.5	38.7 ± 19.4

a. Available waterholding capacity (0.3 minus 15 bar water) expressed in percent per 100 g clay.

Table 4. Relationships between rainfall zone, soil types, and prevailing cereal cropping systems in use in various areas of West Africa.

Rainfall zone (mm/year)	Area	Start of rains	End of rains	Soil type	Cropping system	Harvest period
900-1000	North Ghana	Apr/May	Oct/Nov	Coarse (upland)	Early millet + late millet	July Nov
				Coarse (low land)	Early millet + late sorghum	July Nov
900-1000	South Upper Volta	Apr/May	Oct/Nov	Sandy loam	Red sorghum + late millet	Aug/Sept Nov/Dec
900-1000	South Mali	Apr/May	Oct/Nov	Sandy loam	Maize + late sorghum	Aug/Sept Dec
					Maize + late sorghum	Aug/Sept Nov
600-700	Central Upper Volta and Mali	June	Sept	Loamy sand (upland)	Late millet + cowpea	Oct Oct
		-	-	Sandy loam (lowland)	Late sorghum + cowpea	Oct Oct

uncertain moisture are the rule in the West African SAT except for minor areas with irrigation or along river fioodplains.

Sorghum Varietal Improvement

A great majority of farmers in the West African SAT follow traditional farming practices that have evolved through generations (Swift 1978) and reflect adaptation to the variable environment. Improved varieties and hybrids should be developed to fit these systems if production by farmers, most of whom are near the subsistence level, is to be increased. The failure to have done this may explain the general lack of success of sorghum improvement programs in the region.

Results of Sorghum Varietal Improvement in West Africa

During the early 1960s the Institut de Recherche Agronomique Tropical (IRAT) started work on sorghum varietal improvement in West Africa south of the Sahel. Several promising varieties have been developed in Senegal (Mauboussin et at. 1977). However, in spite of a well-established agricultural research infrastructure as well as a regional experimental unit, Sene (1980) believes that these varieties and research findings have had little impact at the farm level. In Mali and Niger, Sapin (1977) and Chanterreau and Mousa (1977) report that several HYVs have been identified for use by farmers, but Johnson (1979) concludes that in Mali local varieties outyielded the improved ones under moderately superior management conditions.

In Upper Volta, Labeyrie (1977) listed a number of promising varieties. For the northern zone, with 400-500 mm/year rainfall. IRAT S-10 and S-13 were recommended. However, S-10 has proved too late and S-13 required precise soil management for seedling establishment, with the result that neither variety has been generally adopted by farmers. For the 650-750 mm/year rainfall zone (central Upper Volta) several selected local varieties, such as IRAT S-29. Nongomsoba, Belco, Zalla. and Tioadi, were recommended. But again, none is grown on a large scale probably because they are not different from or superior to local varieties already in use. Other dwarf, partially photoperiod-sensitive, improved varieties recommended for the same rainfall zone, such as IRAT S-6, S-7, S-8, and S-10, also have not been adopted because of poor seedling establishment or poor grain quality. In the higher rainfall zones in the south of Upper Volta tall, late-duration, selected local varieties such as Ouedezoure and Gnofing have been relatively more successful, but other improved varieties, such as IRAT 271 and 294, have not been adopted because of poor grain quality.

ICRISAT Sorghum Improvement Program in Upper Volta

ICRISAT sorghum improvement work in West Africa started in 1975. During the following years a range of elite introductions and local varieties have been identified and concepts on varietal requirements have been defined (ICRISAT 1980).

Varietal requirements were considered against variations in rainfall (amount, duration, and distribution), soils (their water-holding capacities), and local farming practices (type of soil preparation, planting dates, and fertilization practices) for the major zones in Upper Volta. As a result sorghum improvement and selection of cultivars of three broad maturity durations were initiated.

a. Long-duration (130-140 days), photoperiod-sensitive sorghum to be planted at the onset of the rains in late May or early June on good deep soils or in low-lying areas where residual moisture is assured at the end of the rainy season. Presently, only local varieties or "improved" locals, outstanding in germination ability, seedling vigor, and drought tolerance, are available. With judicious selection of progenies from crosses of selected locals x elite exotics it may be possible to isolate lines with the hardiness of the locals and the higher yield potential of the exotics. Such work is in progress.

b. Medium-duration (120 days), partially photoperiod-sensitive sorghums for planting in the 600-800 mm/year rainfall zone by the second half of June, or in higher rainfall zones in case of an early drought, providing an additional option as well as a means to spread the early-season workload over a longer period of time.

c. Short duration (less than 105 days), photoperiod-insensitive sorghum that can be planted in July in the northern zone, in the central zone on shalow soils, and as a "last chance" crop where earlier plantings have failed.

Initially, a major emphasis was placed on varieties in the last two maturity groups. Sorghum varieties VS-701 (EC 64734-2), VS-702 (ALAD 324). and VS-703 (2Kx-2Ex21) were extensively tested. Though grain yields were superior, germination and emergence of VS-701 and VS-703 were unacceptably low under farmers' conditions and VS-702 was found to be susceptible to leaf diseases. In 1980. SPV-35 (105 days) and E-35-1 (120 days) were tested with more success.

Strategies for Sorghum Improvement in West Africa

In the previous sections the implications of the environmental factors (soil and rainfall) for growing sorghum were discussed, and the recent efforts in sorghum improvement were critically reviewed. In spite of superior yield performance under experiment station conditions, improved sorghum varieties developed in West Africa have not replaced local varieties and have been rejected by the farmers for intrinsic shortcomings (germination and seedling establishment and grain quality) or because they did not fit into the risk-reducing strategies of subsistence farmers. We conclude that, to define the needs of improved varieties and technologies and to determine their relative priorities, the farming system as a whole needs to be considered, including not only the technical but also the socioeconomic and institutional factors on which these systems are based. It is in this context that a farming system approach (Norman 1974; Hildebrand 1979; Biggs 1980) could help match breeding goals to specific needs of subsistence farmers in the West African SAT.

In view of great diversities in soil and rainfall patterns, the aim should be to increase the number of options (improved varieties and technologies) available to farmers so that they may better cope with these diversities, rather than to propose to them a more or less standard improved agricultural system.

The approach should have three phases: identification and evaluation, technical research, and preextension on-farm testing. These three phases are to a large extent interdependent and should operate simultaneously, as is the case in the ICRISAT Upper Volta project.

Phase 1: Identification and Evaluation

Basically this should provide the framework for most of the subsequent research and testing activities. Being the initial phase, its aim should be to identify and characterize the major farming systems of the region on the basis of:

a. ecological factors (rainfall and soils);
b. technical factors (crops; technological stage of development);
c. socioeconomic factors (availability and cost of production factors; small-farmer production and consumption strategies; marketing systems; government policies).

For comprehensive and integrated results this part of the work should be done jointly by socioeconomists and agronomists using informal-type surveys (Byerlee et al. 1980; Bruce et al. 1980; McIntire 1981) to obtain a qualitative overview of the major systems followed up by more intensive studies for a few contrasting locations. The objective of these "baseline" surveys would be to characterize farming systems in areas not previously studied in detail (this may include developing a typology of different types of small farm groups) to identify their major constraints and to help define the conditions which new varieties or technologies must satisfy for farmer adoption.

During phase 1 it may also be possible to extract useful varieties and technologies for immediate transfer to another system (phase 3) or for use in the technical research (phase 2), as discussed in the following sections. Thus, during the identification phase, efforts should be made to collect and describe the local varieties for those crops that will be used in crop improvement programs in the subsequent technical phase.

Phase 2: Technical Research

On the basis of results from phase 1, it should be possible to indicate the research priorities for the major farming systems in each ecological zone with respect to both sorghum improvement and agronomy.

SORGHUM IMPROVEMENT. Several possible breeding goals suggest themselves to meet the diversity of sorghum growing conditions in West Africa. These strategies include the following activities.

a. Transfer of existing local varieties and techniques either within or between zones in the West African SAT. For this purpose the collection of local sorghums should be tested at several planting dates and at several sites which cover the various ecological zones. This extensive testing is required to identify specific adaptation, pest and disease resistance, and yield stability under late planting—characteristics which could be useful in a future crossing program.
b. Breeding for resistances to yield-reducing factors such as diseases (sooty stripe, *Helminthosporium* blight, grain mold, charcoal rot), insect pests (shoot fly. midge, aphids). and *Striga,* to improve yield stability of local varieties. This strategy basically aims for a step-by-step approach starting from a low-input agriculture, on low fertility soils (being the common situation for most sorghum fields).
c. Breeding hybrids and pure-line varieties for high yields under high input and high management while screening advanced lines for yields higher than locals even under low input and traditional management. This strategy is mainly based on the introduction of exotics and screening the progeny from exotic x local cultivars. These crosses have received the most attention in the past few decades, but have rarely been tested under low management conditions and have as yet made little impact in West African farmers' fields.
d. Breeding for agronomic characteristics to better fit improved varieties into existing systems. Breeding goals may include:
   —varieties with maturity cycles ranging from very early photoperiod-insensitive (100 days) to very late photoperiod-sensitive materials (150 days);
   —greater tillering in order to allow for a lower plant population or for compensation of plants lost in early droughts; and
   —greater compatibility with intercrops, particularly cowpea, by changing plant structure (for instance plants with fewer and narrower leaves).

AGRONOMY. For many situations in West Africa various agronomic constraints appear to be more serious than genetic limitations of local varieties and will need more emphasis in the future if the merits of improved varieties are to be fully exploited.

Since commercial inputs are expensive and often unavailable to most farmers, the major agronomic strategy of ICRISAT in Upper Volta and Mali has been to exploit to a maximum the environmental factors (soil and rainfall) and biological factors (cropping systems, rotations, and plant types). Results of these efforts have been presented in several papers (Stoop et al. 1980; Stoop and van Staveren 1981). Two key agronomic problems are common to many parts of West Africa, and need special attention: maintenance of soil fertility, and erosion control. The latter, especially, is connected with overextended farms and the poor use of animal equipment (repeated plowing and cropping of natural drains).

Phase 3: Preextension On-farm Studies

In many tropical countries there is a rather strict separation between research and extension. As a result many scientists are not actively concerned with the adoption of their improved varieties and technologies by farmers, and thus remain unaware not only of farmers' constraints but also of the possible shortcomings of their proposed improvements. Likewise, the reasons for the shortfall between yields realized on-station and those under farmers' conditions are rarely critically analyzed (ICRISAT 1981). In response to this situation many of the International Agricultural Research Centers have started to promote on-farm testing in their training (CIMMYT 1978) and outreach programs.

On-farm testing must involve more than just placing a number of plots in farmers' fields to evaluate and demonstrate a new variety or technique. Rather, one can distinguish between "on-farm trials" and "farmers' tests". The former consists of controlled experiments managed by researchers but located on farmers' fields under more representative soil, disease, and pest conditions than on a research station. The latter, "farmers' tests", are not only situated on farmers' land but are also managed by farmers who are free to modify the recommendations. Such modifications may represent points of conflict with other elements in the farmers' operations and, as such, are analyzed as farmer-introduced treatments. Intensive input-output data are collected for the test results as well as for other fields of participating farmers in order to place the test results in the more comprehensive context of all household farming activities.

Farmers' tests provide an insight on a range of questions that concern the practical utility of new varieties and technologies, as follows.

—What is the performance of a new technology under a range of farmers' environmental and management conditions?
—What factors operate under farmers' conditions that are not seen in the research station?
—Are there conflicts in the quality, level, or timing of resource use with farmers' capacity?
—What are the financial and economic returns compared with alternate activities?
—Is the technology consistent with farmers' consumption goals?
—What are the consequences of adoptions?

It is emphasized that the ultimate purpose of such farmers' tests should be to feed back into the technical research phase a better understanding of the merits and limitations of the technologies under development. In this sense, farmers' tests should not be viewed simply as final preextension screening but as an integral part of the technology development process itself. Likewise, farmers' tests may not always be an essential requirement for extension as long as satisfactory results of on-farm trials are available.

The farmers' testing phase described above was introduced in the ICRISAT Upper Volta program in 1980 with cooperation between sorghum improvement, economics, and agronomy programs. The white sorghum variety E-35-1 was tested in two villages near Ouagadougou against local varieties. Results of these tests helped identify certain limitations of this variety under farmers' management and led to modifications in research-station screening and selection methods. The tests also helped identify conditions in which the improved variety and recommended practices were superior (Matlon 1981).

An expanded program of farmers' tests located in several agro-climatic zones is being implemented by ICRISAT/Upper Volta during the 1980s. These tests are being designed as a follow-up to village baseline studies already under way. This program offers an opportunity for collaboration between several disciplines at the farm level to help define research objectives, thereby reducing the time necessary to arrive at improved technologies truly adapted to the needs of the West African farmer.

Acknowledgments

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Grain Postharvest Technology for Developing Countries

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In the past two decades, considerable emphasis has been placed on increasing production of cereal food grains to meet the needs of the world's growing population. Success has been achieved in several parts of the world, as evidenced by the "Green Revolution". However, in other regions the rate of grain production increase has not kept up with the rate of population increase.

In 1977 the total worldwide production of grains was estimated to be 1.46 billion metric tons. If a world population of 4.4 billions and per capita need of food grain of 200 kg are assumed, more than enough grains are produced to feed the world population. However, there is a problem of highly unequal distribution of grain supplies. Furthermore, considerable amounts of grain produced are used for feeding animals and other industrial purposes, and do not reach the consumers.

Postharvest grain losses (physical or weight) are estimated at anywhere from 5 to 40% for many of the developing countries. At best, these figures are rough estimates, and in only a few cases are documented studies available to show actual measured losses. In addition to the quantity of grain lost, it is believed that considerable grain quality loss is experienced in developing countries. This is of vital importance to subsistence-level families because their daily nutritional requirements are extracted mainly from cerea grains.

Grain lost after it has been harvested not only loses the monetary value of grain and the availability of food supply, but also the inputs and efforts that have gone into growing the grain. Some loss is undoubtedly inevitable but there is much that can be done to preserve the valuable food grains that are produced. Unfortunately, in many cases where production has increased through proper uses of improved seeds, fertilizers, water, and chemical pest control measures, we have not had the foresight to plan ahead and provide proper and adequate grain storage facilities, grain marketing systems, and other infrastructures to preserve the quantity and quality of food grains so that producers and consumers alike are benefited.

Let us briefly examine the magnitude of grain loss experienced annually in the world. Based on the FAO estimate of a 10% annual harvest loss, and the total grain production in 1977. approximately 146 million metric tons of grain are lost. This loss would have fed about 730 million people or would translate into the loss of about 30 billion dollars (based on the average price of $ 200/ton). The postharvest grain loss should be a more vital concern in developing countries where the domestic demand for food grains outstrips domestic production because the increased food grain imports put a tremendous strain on the foreign exchange reserve.

In developing countries, most of the farmers are at the subsistence level and their land holdings are very small. Quantities of grains held on the farms generally range from 70 to 90% of their total production, and only 10-30% of the grains produced leave the farms for domestic grain marketing channels. Current grain handling, storage and drying methods and facilities employed on farms in developing countries are quite inadequate for the proper preservation of grain.

Despite these facts, little attention is given to the improvement of on-farm postharvest grain systems in developing countries. It is indeed ironic that sums of money are spent on increasing production only to lose a substantial amount of the grains produced.

Therefore, it should be recognized that im-

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proved postharvest grain systems are a vital need in the developing countries.

Postharvest Grain Systems

Grain produced flows in a multitude of paths from producer to consumer in developing countries. Figure 1 illustrates the complexities that may be encountered in this flow. No two countries seem to have the same marketing patterns or networks. Whatever pathway grain takes from producer to consumer, the following functional elements are involved in postharvest grain systems: harvesting, threshing, cleaning, drying, storage, handling, transportation, grading, marketing, processing, and utilization.

Each functional element includes a physical facility, its operation and management, and grain management. Postharvest grain systems can be divided into three subsystems: (a) the farms, (b) the commercial operations, and (c) the government operations.

Status and Problems of Grain Storage and Drying at Farm Level

In developing countries, grain quantities held on the farm generally range from 70 to 90% of the total production. There are of course exceptions. However, the general rule is for the major portion of the grain produced in developing countries to be stored on farms. Grain crops are harvested and threshed almost always by hand except for a very few commercial and experimental farms. All crops harvested are, in most cases, dried by a natural, sun drying method and stored on the farms at some time, whether they are destined eventually for sales or for on-farm consumption.

The storage period of grains intended for sales may vary from a day to a few months but in many cases the farmer sells his crops at the time of harvest. It appears that the main factors influencing the decision on how much to keep and how much and when to sell are:

1. The amount of the total crop harvested.
2. Availability of alternatives for on-farm consumption.
3. Storage capacity.
4. Cash commitments (debts, supply of goods, etc.)
5. Availability of time and labor at harvest period.
6. Availability of transportation.
7. Weather conditions.
8. Prices.

Grains are stored on the farm in various forms of storage generally for periods up to 10 months. The different types and sizes of traditional storage units are constructed from locally available materials such as mud and plant materials. On very rare occasions nontraditional materials for a grain storage such as metal, concrete and brick are used. In many of the developing countries bags of cereal grains are stored within human dwelling. In many countries in Africa small quantities of grain may be stored in dried gourds or other small containers. Sorghum and millet in head are stacked on platforms and covered with thatch to ward off rain. The size of farm storage units in developing countries would range from a few hundred kg to a few tonnes. At any rate, farm storage in most of the developing countries leaves grain supplies vulnerable to insects, rodents, birds, and to deterioration due to molds (high temperature and humidity regions).

Research is under way in some areas to develop improved storage facilities for farm use. One of the main weaknesses in developing new types of storage facilities for farm use in developing countries has been the lack of socioeconomic considerations. Can the farmer afford to build an improved storage unit and is he willing to adapt it? With a high cost of improved storage and the absence of reasonable access to market by the farmer, he may perhaps be better off to absorb the losses he experiences rather than to invest in improved storage.

Although there is often an expressed interest, on the part of governments, in the need for improved farm storage, it has become apparent that the major emphasis is usually directed from elsewhere. Most of the studies on farm storage have been conducted and/or financed by multilateral international organizations. Some studies have been conducted by individual countries, but such studies are exceptions rather than the rule.

In developing countries, removal of excess moisture from crops is normally carried out by sun and wind drying. If poor climatic conditions (high humidity and rainfall) following harvest make this operation impossible or extend the drying period, quality and quantity loss may be high and rapid. In

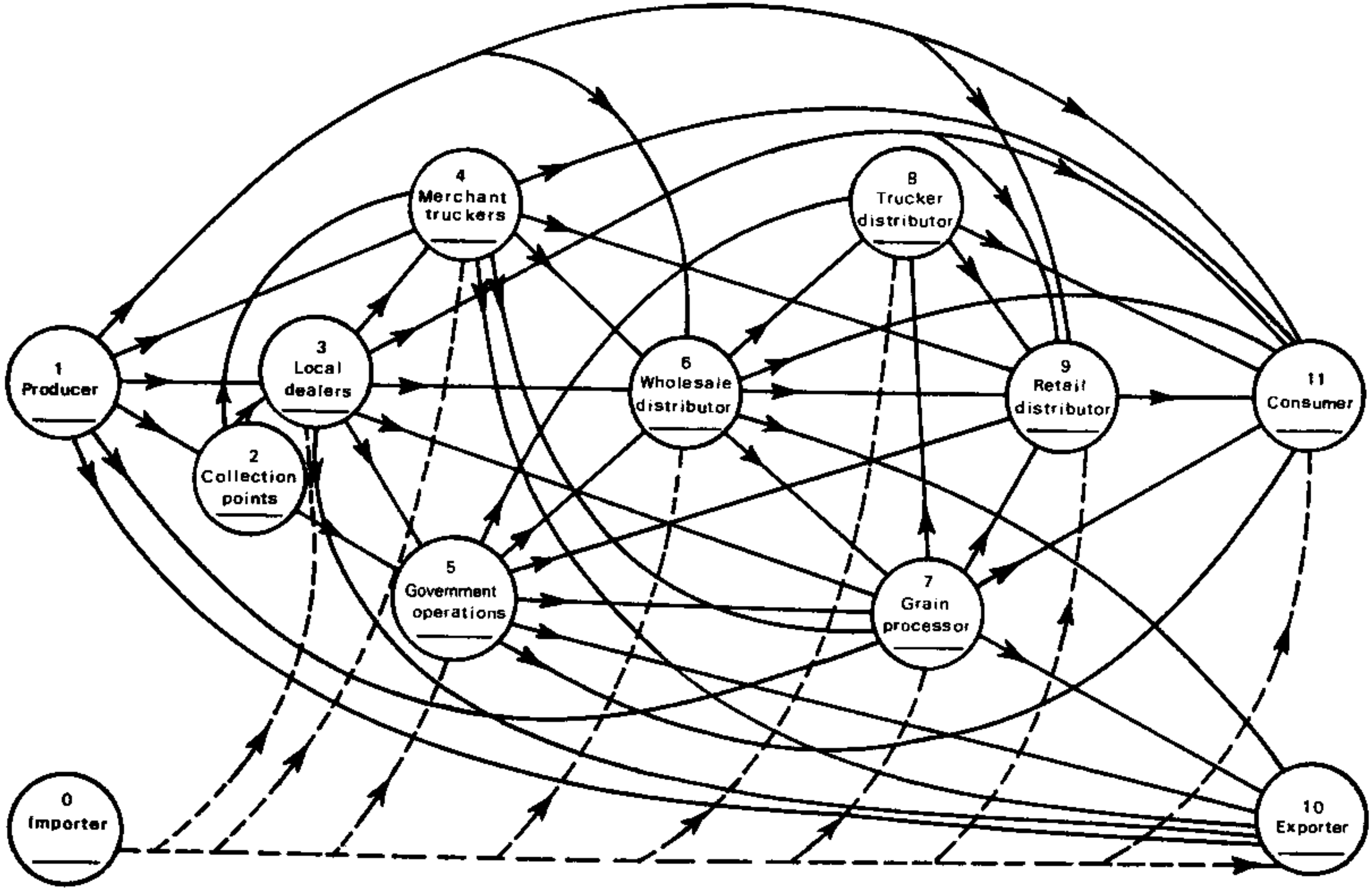

Figure 1. Grain marketing flow patterns.

most developing countries, farmers are forced to sell their crops at the time of harvest because they lack the facilities for drying and storage.

Sorghum and millet in head are usually dried on platforms of various sizes supported by a wooden framework raised 3-4 feet off the ground, with heads piled to various depths. Rough rice and other threshed crops are spread on the mat for sun drying. The drying methods used on the farm in developing countries are, in general, unsound except for economic consideration. Considerable quantities of grains can be saved and preserved if a simple, economic drying method is available when sun drying cannot be accomplished.

The main causes of grain damage and losses are the improper and inadequate grain handling, drying, and storage methods employed on the farms. Reduction of losses through improved facilities has been used as justification for the new facilities. However, new facilities in themselves will not prevent losses. An equally important aspect of safe grain storage is to employ good management practices. These include examining grains periodically for signs of heating, insects, mold, and rodents; good housekeeping and sanitation in and around the premises; cleaning of grain; maintaining uniform moisture of grain; and chemical pest control measures. However, such practices are not well followed on farms because of a lack of understanding of grain storage fundamentals by farmers. On very rare occasions, chemical pest control measures are used. Other pest control measures used occasionally by farmers include ashes, smoke from cooking fires, rat guards made of tin cans, and cats for rodent control. In spite of the fact that grains are stored under adverse conditions for proper grain preservation, individual farmers in developing countries are taking reasonably good care of grain during storage because they need this food supply until the next harvest.

In addition to the problems mentioned above, the first links in the movement of grain off the farm into major marketing channels, "first collection points", are often missing in developing countries. The existence of poor postharvest grain facilities at the farm level is perhaps not the main drawback, but rather the lack of development of a marketing system, i.e., roads, transport facilities grading systems, market news, etc. Other problems that exist in developing countries are the lack of technical personnel familiar with postharvest grain technology, and the very sporadic existence of government organizations or other institutions responsible for the development of improved on-farm postharvest systems.

With a very few exceptions, there exist virtually no formal programs or concerted efforts by governments of the developing countries for developing improved postharvest grain systems. However, it is encouraging to note the recent establishment of the Southeast Asia Cooperative Postharvest Research and Development Program (SEARCA) by the five ASEAN countries. This program is administered by high level administrators from each of the five countries and is responsible for formulating improved postharvest grain systems for Southeast Asia. The SEARCA technical team is supported by various donor agencies (i.e., IDRC, USAID, RTI, CSIRO. etc.).

In addition, there exists the Group for Assistance on Systems relating to Grain After Harvest (GASGA). GASGA members are:

The Food and Agriculture Organization, UN (FAO).

L' Institute de Recherches Agronomiques Tropicales, France (IRAT).

The International Development Research Centre, Canada (IDRC).

The Food and Feed Grain Institute, Kansas State University, USA (FFGI).

The Tropical Products Institute, England (TPI).

International Institute of Tropical Agriculture, Nigeria (IITA).

Deutsche Gesellschaft fur Technische Zusammenarbeit, Germany (GTZ).

Koninklijk Institute voor de Tropen, Netherlands (RTI).

Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO).

Each GASGA member institution is actively involved in technical training and conferences, and appropriate technology development for postharvest grain systems in developing countries. Under a cooperative agreement between the Food and Feed Grain Institute, FFGI, Kansas State University, and USAID/Washington, FFGI has been providing technical assistance on grain storage, drying, processing, marketing, and agri-business development for many developing countries.

Suggestions and Recommendations

Interest and concern for these postharvest problems have arisen only in recent years. While many countries have not yet recognized the importance of improving the postharvest grain system for reducing grain loss and improving the efficiency of operations, international agencies and organizations are becoming increasingly aware of this problem. Possibly the strongest support for a coordinated postharvest program came from the Jnited Nations Resolution of September 1975, calling for a 50% reduction in postharvest food losses by 1985, and the cooperation of all countries in attaining this objective. Recognition of its importance alone is not enough; rather, there should be a strong and long-term commitment by the governments with sufficient allocation of resources and concrete efforts through cooperation, coordination and communication by many concerned groups (i.e., government, scientific community, private sector, producers, international agencies, etc.), in order to have successful postharvest grain technology programs.

The following suggestions and recommendations for improving the postharvest grain systems in developing countries are given, based on our observations in many developing countries and on the paper, "Priorities for Action in Grain Postharvest Loss Reduction" prepared by GASGA members, (FAO, IRAT, IDRC, KSU and TPI):

1. Institutional Development

As mentioned in the preceding section, in general the governmental organization solely responsible for improved grain postharvest systems in the developing countries is virtually nonexistent. It is important that all postharvest planning and activity should be closely integrated and coordinated. Therefore, it is suggested that a postharvest division or section be established within the ministry of agriculture.

A technical support unit is also essential to the planners in postharvest systems. Such a unit will require a cadre of special staff experienced in postharvest technology, marketing, training and extension. Adaptive research and training programs are also essential for the development of improved postharvest systems in the developing countries. These can be best achieved through the establishment of a postharvest research and training center attached to an agricultural college or the ministry of agriculture. While the above technical support unit can be initiated with the assistance of donor agencies and foreign experts, it should, as soon as possible, be staffed at all levels by local personnel and be financed from local funds. In this way, continuity of effort and local experience can be obtained for the backup of the long-term plans and programs.

2. Training

The unavailability of adequately trained and experienced manpower is one of the major constraints in developing improved grain postharvest systems in developing countries. The development of well trained individuals for grain postharvest areas is a complex and time-consuming process. It will require many years before well trained teams of agronomists, entomologists, economists, engineers, agricultural chemists, microbiologists, food technologists, nutritionists and extension workers are available to provide the coordinated leadership necessary to improve grain postharvest systems in developing countries. Foreign advisors can assist concerned nationals to start the training program, but in the long run only competent professionals from the country itself, who know its environment, history, traditions and values, will be able to develop and maintain the programs.

There is a basic need for training programs in postharvest technology directed toward farmers' training institutes, extension services, and agricultural colleges. Graduate-level training in the grain postharvest technology is necessary for the establishment of a cadre of professional staff. Perhaps, the greatest need is the establishment of in-country training aimed at the lower groups of staff of government agencies, inspection and pest control services, extension services, etc.

Many donor agencies are active in providing training for graduate and senior level staff in technical institutions in their own countries and in assisting in-country training programs. Research and training institutes in both developed and developing countries must cooperate to devise better and faster methods of delivering the required training to the developing countries.

3. Adaptive Research and Development

From the preceding section, it is evident that the adaptation, development, and transfer of technologies for the improvement of current grain handling, drying, storage, and processing practices in the developing countries are definitely needed.

The first concern of research and development programs should be the utilization of the present knowledge in the location. The next requirement is for research into specific local problems which are not answered elsewhere. It is essential to establish a balanced research program to provide a base for short-term research and an adequate research environment to train local graduates and technicians. Eventually persons best equipped to solve the problems, for example, in India are the Indians. Each country's problems are separate and distinct and even though the basic technical aspects of the grain postharvest systems are the same in each of the countries, there are definite values in solving one's own problems. Also, the importance of establishing and maintaining a positive link between research and extension efforts should be recognized, and close cooperation and communication between international research organizations and/or technical universities in the developed countries, and the research organizations in the developing countries, should be actively sought.

Any developments in grain postharvest technology should not only be technically sound but also socially and economically sound so that they can easily be adapted in a given developing country. A few priority areas for research activity are outlined below:

- Extensive surveys on grain quality and quantity losses under various traditional grain storage methods on farms with a standardized loss assessment methodology.
- Investigation to improve best types of current traditional storage facilities and methods.
- Investigation to develop a simple and effective nontraditional type of storage facility by considering climate, locally available materials, type of storage, level of technology, etc.
- Investigation to develop drying systems that will be suitable for the subsistence level farmers. Special consideration should be given to the reduction of energy costs, by improving thermal efficiency of dryers or by research into new sources of energy. Efforts should be made, in particular, to maximize the use of agricultural by-products such as straw, chaff, husks, etc.
- Investigation to develop effective pest control methods.
- Investigation to develop small threshers which can be carried from farm to farm or to the field, and can thresh efficiently under normal local conditions.
- Investigation to develop small cleaners which can clean grains efficiently under normal local conditions.
- Investigation to develop a simple and inexpensive method to determine grain moisture content with reasonable accuracy and precision.
- Investigation to develop a simple grain grading method.
- Investigation to improve nutritional levels in rural areas.
- Investigation to improve cereal processing methods and equipment, adaptable to present technology and social patterns.
- Investigation to develop agribusiness firms or agricultural processing industries near the rural area (e.g., grain processing, feed mills, rice mills, agricultural implement manufacturing firms, agricultural supplies and service shops, etc.).
- Investigation of the design and location of suitable grain collection stations that will allow farmers reasonable access to the markets.

4. Extension

Shortage of extension staff in the developing countries is another constraint in the establishment of improved grain postharvest systems. Existing agricultural extension services are almost entirely directed to problems of production. Most personnel employed in extension services have little knowledge of the grain postharvest field. Therefore, it seems essential that training in postharvest technology should be given to those extension workers who are in direct contact with farmers.

Finally it is hoped that the importance of improved grain postharvest systems is recognized. The improvement of grain postharvesting systems in developing countries is considered to be an integral part of the overall improvement of sorghum in the eighties.

Session 6 Production Technolgoy

R. V. Vidyabhushanam* Discussant—1

Sorghum, especially in the traditional areas of Asia and Africa, is usually grown in harsh environments. The level of management in traditional dryland subsistence agriculture in these countries is poor. In recent years, considerable emphasis is being given in several of the developing countries to evolve superior genotypes capable of giving high yields. This is quite important in India which has the largest area sown to sorghum in the world. The attempt has been total transformation to stable and high levels of production. This necessitates evolving new production technology capable of realizing the full yield potential from new genotypes.

Cropping Systems

In traditional dryland agriculture, the practice of mixed cropping is extensively followed and serves to cover risk against unpredictable seasonal conditions. The cultivation of early maturing high yielding hybrids and varieties of sorghum was found to reduce vulnerability to adverse seasonal conditions thereby leading to stable and higher productivity. In this context, the cropping systems evolved should be able to (a) furnish better risk cover in subnormal years and greater profitability in normal years, (b) enrich cereal diets and soil fertility through incorporation of legumes in the system, and (c) improve land-use efficiency and increase overall productivity.

Evolving appropriate cropping systems for inter and sequence cropping situations suited for the short and early maturing genotypes has been an integral part of the strategy for enhancing production and productivity of sorghum lands in India. To this effect, a large number of studies have been carried out during the past decade in the All India Coordinated Sorghum Improvement Project and the All India Coordinated Research Project on Dryland Agriculture. The results from these studies clearly demonstrated the profitability of the sorghum based intercropping systems with different legumes (pigeonpea, cowpea, greengram, groundnut, soybean, etc). In terms of monetary returns, the increase ranged from 10 to 50% of the sole crop depending upon the location and the intercrop. The sorghum-pigeonpea system was found to be the most profitable combination.

Dr. Willey and his colleagues in their paper on sorghum-based cropping systems have skilfully reviewed the work done in various countries. It is evident from their review that opportunities for utilizing sorghum in various cropping systems are indeed unlimited. Besides yield advantage, several other benefits from intercropping have been listed. For India, the inclusion of food legumes or oilseed crops in the cropping systems with sorghum is extremely important in view of the acute deficit the country is facing for pulses and edible oils. Apart from increasing the production of these scarce commodities, the beneficial effects of nitrogen fixation by legumes is also an important consideration. It is, however, significant to note that substantial benefits of nitrogen fixation by groundnut could not be observed from ICRISAT studies. It is suggested that detailed studies be undertaken to quantify the beneficial effects of nitrogen fixation from various sorghum-legume combinations. The possibility of sorghum-chickpea intercropping in the postmonsoon *(rabi)* season deserves to be further explored.

The finding that in a high rainfall, deep Vertisol situation like Indore, the probabilty of taking a successful second sequence crop is only 27%, is revealing. The reason attributed for this low probability is the nonavailability of adequate soil moisture in the surface layers. This aspect needs

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to be investigated further to devise some tillage methods to conserve the moisture in the surface layers, because there is a vast potential for a second crop in this area if short-duration sorghum hybrids are eventually cutivated on a large scale.

Opportunities for taking a ratoon crop exists now with the introduction of short-duration, photoperiod-insensitive hybrids. Slow senescence and quick regeneration are the advantages of these hybrids. The observation that ratoon crops yield only about half of the planted crop is applicable to situations where moisture is limiting. Under adequate moisture situations or where one or two supplementary irrigations can be provided, yield comparable with the seed planted crop can be realized.

The suggestion made in the paper that genotypes suitable for intercropping be identified or bred, taking into consideration the desirable plant characters, is very appropriate. This applies to both sorghum as well as to the intercrop.

Seed Production

Seed production is the crucial link in crop improvement programs through which superior genotypes developed by the plant breeders reach the farmers. The main purpose of the seed industry is to generate adequate quantities of good quality seed of high yielding hybrids and varieties.

Dr. Chopra in his paper presented a comparative account of seed production aspects in developed and developing countries and posed some of the problems faced by the seed growers in the developing countries regarding sorghum seed production. I wish to highlight some of the important features of the organizational system and growth of the seed industry in India.

An organized seed industry on commercial lines came into existence in the mid-sixties with the release of hybrids of sorghum, maize, and pearl millet. At present, India has the largest seed industry in the developing world. Indeed the growth of the commercial seed industry in the country is phenomenal. Seed is produced and distributed both by public and private agencies and a healthy competition exists between them, which is ideal for the rapid growth of the industry. The estimated annual production of certified seed of sorghum hybrids is of the order of 12 000 metric tons.

Seed production with sorghum hybrids is concentrated in some favorable areas along with some other isolated pockets, mainly in the peninsular region of the country. Seed production is being taken up both under rainfed conditions in the monsoon season and with irrigation in the winter-summer seasons. Several thousand small and big seed growers are involved in the production of hybrid seed. By and large, they are receptive, and acquire the necessary technical skill, to carry out seed production programs effectively.

A number of problems are encountered in the production of hybrid seed some of which have been referred to by Dr. Chopra. They include the adequate and timely supply of breeder's and foundation seed, nicking and low germination problems in some hybrids, and matters associated with seed certification regarding isolation, etc.

At present, the situation on production and the timely supply of breeder's and foundation seed is somewhat critical due mainly to the frequent failures to obtain expected yields in the seed plots. To overcome this difficulty, the suggestion made by Dr. Chopra to create buffer stock of breeder's seed to last for 3-4 years is very relevant. As regards foundation seed, two important decisions taken recently by the Government of India would go a long way towards eliminating these shortages. The first relates to the removal of restrictions to organize foundation seed programs by the private seed companies to meet their own requirements, and the second is to permit stage II multiplication of foundation seed.

The problem of nicking in the production of certified hybrid seed is bound to exist because production is attempted in variable seasons and climatic conditions. While it is possible to overcome this problem under irrigated conditions by staggered plantings and agronomic manipulations, such alternatives are not possible in rainfed situations. In the irrigated fields, seedlings are raised in nurseries and transplanted at an appropriate time. This has proved to be highly successful in the case of the CSH-5 hybrid where there is a major nicking problem. This procedure has other advantages such as a lower seed rate, better shoot fly control, and more uniformity of crop stand and expression.

The problem of grain mold is rather acute in many seed production areas due to the prevalence of humid conditions. They frequently reduce the germination of seed rendering it unfit for certification. Fugicidal spray schedules have been found to be very effective in minimizing the problem of lower germination.

A lot more work still needs to be done in the area of seed technology to make seed production a more attractive proposition. The success and popularity of a hybrid depends as much on its yield potential as on the easy producibility of seed. It should be the constant endeavor of plant breeders to develop hybrids that have minimum seed production problems.

Session 6 Production Technology

L R. House* Discussant—2

An important use of sorghum is as an intercrop. There are numerous combinations: sorghum in maize in Central America, sorghum in cowpeas in Brazil, sorghum in millet in West Africa, and sorghum in pigeonpea in India, serve as examples. Beside space relationships there is concern about modification of the plants themselves, usually in terms of plant height and maturity. This is a debated issue; an example will help. There is a situation in India where there is interest in the dry sowing of sorghum and pigeonpea before the monsoon rains. It is valuable if the sorghum crop can be harvested in mid September as the pigeonpeas begin to expand; however this is a period of expected rainfall resulting in the weathering of the sorghum grain. It may be possible to use a later-maturing type with erect leaves and/or long internodes between uppermost leaves to reduce competition with the pigeonpeas.

There is concern both for the poor farmer of limited means and in producing adequate food to meet demands. The concept of a two-pronged thrust directed at a rapid increase in production in areas of less moisture stress while contributing to improved production capability of the poor farmer in climatically harsher areas was mentioned and is of interest at ICRISAT. In addition, the concern for increased production in already highly developed agricultural situations was recognized and is important to our concern about availability of adequate quantities of food.

I have been impressed by the precision of sowing gained with some tractor-mounted planters and the resultant effect on stand. This heavy equipment moves the soil rather than being moved by the soil; so, for example, seeds can be placed at a desired depth, seed, fertilizer, soil insecticides, and herbicides can be placed precisely and uniformly, and uniform interrow spacing permits easy cultivation. It would seem that some concepts from this kind of tractor-drawn equipment could be adopted to simple animal-drawn tools. The addition of simple guage wheels to control depth of sowing, rolling disc planter shoes to slice rather than drag through the soil, some form of press wheels to firm soil around the seed; guide discs to reduce side slip, and a marker to better judge interrow distance may be adopted to existing farmer equipment. The value of animal-drawn tool carriers is recognized and their effective use demonstrated. A closer look at the possibility of improving yet simpler equipment is questioned.

Weed control is undertaken in many areas by hand pulling or the use of a simple hand tool. An improvement in methods of weed control would permit more timely weeding at lower costs. Weeds can be a major constraint to production and their control deserves more attention, particularly in the developing countries.

The concept of minimum tillage has evolved in developed countries. A problem has been slower warming of the soil following the cold winter, there being as much as 5°C difference between fully tilled and minimum tilled fields. This may be of interest in tropical areas where soils are frequently very hot at the time of sowing. This is an aspect of the general problem of stand establishment, the concern for which has been mentioned.

The idea of using sorghum to conserve water for irrigation in areas where the water table is not being adequately recharged is interesting. The concept of protective irrigation in India developed years ago. The concept of sorghum as a water efficient plant could be important in a range of situations where water availability is limited. Effective policies to help ensure water use in this way are important to this consideration.

The importance of biological nitrogen, and

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cautions in its promise, have been mentioned. Surely, this will be an interesting and important research area in the 1980s.

At this symposium we have been primarily concerned about food. Farmers in India using high yielding hybrids have found the processing of stover into hay different and more complex than with traditional varieties. There is an opportunity to improve the value of sorghum stover as hay as part of our research. This could involve nutritional improvement of the plant as well as processing procedures.

The concept of improved mechanization of farming displacing some farm labor but resulting in an increase in job opportunity is valuable. So frequently there is concern about techniques that displace labor. This concept of labor-saving and labor-efficient devices should not be overlooked in a transitional situation that could finally lead to increased job opportunity.

The importance of crop management on experiment stations has been mentioned. The importance of this is obvious but frequently overlooked. Many well trained scientists fail to have satisfactory conditions of field research.

Important to concepts of crop management are those of pest management. Early sowing of sorghum in the monsoon season in India will avoid the shoot fly; large area sowing of varieties with the same maturity at the same time has been demonstrated to assist in control of the midge; and modification of crop maturity and date of sowing may help to avoid crop depredation by birds. The destruction of crop residue to remove the carry-over of stem borer is another among the numerous possible examples. The considerations of interaction of crop management on pest control should be included in crop production research activities. It may also be valuable in areas where midge is known to be a problem to encourage large area planting of earlier varieties and hybrids at the time of release.

Extension services are frequently condemned for lack of effectiveness; less often is the question asked about developments from research that are useful to extend. The use of animal-drawn machinery in southern Mali, and of seeds of high-yielding varieties and hybrids in India over the last 15 years are examples of a response by farmers to something of value to them. In both situations an entreprenurial group in the farming community comes forward and in fact creates demand for an even greater input—such as the use of tractors in southern Mali. That farmers in traditional situations will effectively respond to new technology useful to them as well as apply pressure on government for a change in policy and availability of inputs needs to be more widely recognized and understood.

The argument that the development in southern Mali rests on the production of cotton, a cash crop, is relevant in that it provided a basis to generate income. It is significant that farmers in the project area also used their equipment and better management procedures to improve sorghum yields. In fact, the project targets three times the area in cereals as compared with cotton. It is likely that with suitable crop technology in better watered areas such as southern Mali, yield returns from cereals can be sufficient to cause the same changes as those catalyzed by cotton. The concept of a quantum increase in yield is recognized as one possible way to generate change.

Where does the farmer turn for help? What can the extension man or researcher tell a man farming a low-lying waterlogged area when there is no community system for drainage? New machinery can be developed but who produces it and who ensures quality standards? Some such activities are extension oriented, some are project oriented, and some require government regulation. The question of where the farmer can turn for effective technical information and support is an important question for the eighties.

The concept of quality seed as an important component of developed agriculture is recognized but all too frequently without adequate conviction. This can in part arise from a frustration in the absence of the ramifying infrastructure required.

The largest most successful seed enterprises in the world exist where competition and profit incentive are important motivating forces. Governments interact to maintain some regulation of companies but they are not involved in competitive seed production and marketing activities. There are currently countries where superiority of sorghum hybrids has been demonstrated and these are likely to increase in the 1980s. Opportunities for private company operation varies but of basic importance is a conscientious study by governments into ways of efficiently producing and marketing quality seed. Independence of the seed production and quality control aspects is important. The role of quality control, research, and extension as functions of government and of seed production by autonomous independent agencies requires consideration. Regional marketing of hybrid seed may well be a viable alternative, particularly in parts of Africa.

A seed industry has developed in India over the last 20 years—this system warrants careful study. A problem has been inadequate quantities of hybrid seed. Aside from policy issues important to this problem, are the constraints in the actual production of seed. If it is difficult to achieve nick (the simultaneous flowering of both parents) in the production field, seed yields are low. The problems contributing to nick can be solved but this requires time, delaying availability of adequate seed stocks of new hybrids, and smaller producers may not attempt the production of seed of hybrids where nick is a problem. As production of hybrid seed begins in a country, particular care should be taken to ensure easy production over many possible areas suitable for this activity. It is not unrealistic to insist on a test demonstrating produceability as a criterion for release. At ICRISAT, as we develop new A-lines we are selecting sister A - B lines that range in maturity by as much as 10 days. The idea is to increase option in the A-line to match flowering with an R-line in production fields. Other techniques can be developed to improve nick in hybrid seed production fields and these developments should be encouraged.

Maintenance of type is a matter of concern. Breeders developing new hybrids should accept the responsibility of insuring type in nuclear seed and breeder's seed. Without this, the hope of maintaining type in foundation and commercial production fields is poor. Certification, and a vigorous determination to maintain certification standards at all stages of seed development, will contribute to the quality of seed that the farmer buys.

The importance in a country, where there is interest in hybrids, in recognizing major differences in production and marketing of hybrid vs variety seeds cannot be overemphasized. The production of hybrid seed offers a valuable opportunity for quality control and for extension in encouraging better farming practices. The success or failure to make an impact with hybrid seed depends on the program evolved. At a minimum a country should take the time to study carefully the seed industry where it is established and to modify and adapt concepts to local conditions.

The issue of technical assistance in establishing a seed industry is important—where do people go for help and expertise? A careful look at some of the functions of the National Seeds Corporation in India is worthwhile.

The issue of postharvest technology has been considered from modification of traditional means to rather sophisticated systems. The need to be aware of and to respond to changes due to increased urbanization in the 1980s as related to seed processing, storage, transport, and marketing requires our attention.

Session 6 Production Technology

Discussion

Norman

ICRISAT is to be congratulated for taking a leadership role in intercropping work thereby helping to make research in this area a respectable occupation for scientists. Dr. Willey has clearly shown the possible advantages of intercropping in increasing land productivity. Have you looked at the potential of intercropping to increase the productivity of labor at critical bottleneck periods? In West Africa, intercropping is commonly practiced by farmers with labor rather than land limitations. Productivity of their labor input during the critical weeding period is increased by growing crops in mixtures rather than as sole stands. (Factors contributing to this are increments in gross yield per hectare through growing the crops together, i.e., LER 1—and higher stands per ha—i.e., millet plus sorghum compared with millet or sorghum sole crops —which may reduce weed problems). The potential for improved techniques for intercrops in labor scarce areas, particularly for farmers using hand tools, is great. This is especially the case when yields of improved technologies for sole sorghum are not spectacular thereby often resulting in a decrease in the return per unit of labor input during the critical period compared with the traditional sorghum technology. A complementary intercrop would in such interaction help increase the return per unit area and per unit of labor thereby helping the adoption of improved yield-increasing sorghum technologies in labor scarce areas. This has in fact happened in parts of northern Nigeria where long cycle SK5912 sorghum is often grown by farmers in mixtures with short cycle traditional millet. Incidentally some of Andrew's work indicates that animal traction is possible with intercrops. In order to get the labor factor into designing and analyzing improved technological packages, it is necessary to pay increasing attention to work at the farm level.

Willey

We have not specifically looked at intercropping productivity per unit of labor input, though we are aware of your work on this aspect. As with any cropping system, it is obviously logical and useful to examine productivity against any resource that is particularly limiting. For most operations (e.g., cultivations) labor inputs are unlikely to be greater for one hectare of intercropping than for one hectare of sole cropping, and for important weeding operations they can be less. The higher productivity per unit area from intercropping will thus often give higher productivity per unit of labor input.

House

In terms of yield, varieties developed at ICRISAT Center have not really contributed as compared to locals when both are grown on farmers' fields in drought prone areas of West Africa. We are making an effort to use heterosis in order to obtain an increase in yields. There is interest in hybrids but the available information suggests that in dry areas this is not an easy job. We are looking at the possibility of sorghum synthetics. The West African types are very open-headed and natural outcrossing may be sufficient. Bhola Nath at ICRISAT is beginning to use ms_3 and ms, to build a composite that a farmer can use with the sterility remaining in the population. We are also interested in what opportunities may come from apomixis.

Balasubramanian

Dr. Willey made an interesting observation that nitrogen fixation of groundnut in intercropping with sorghum was reduced. Was it due to reduction in plant size or due to fewer nodules?

Willey

Plant size, nodule number, nodule weight, and fixation rate can all be reduced in intercropping but the point I was making was that our microbiologists have found that even where plant size is not reduced, fixation rate often is. Current evidence is that fixation is preferentially reduced because of shading compared with normal physiological processes.

Niangando Oumar

In our experiments on sorghum-millet intercropping with cowpea, an absence of grain production from cowpea was observed. Have you noticed a similar phenomenon during your research. Is it a varietal or physiological question?

Willey

This is not a problem we have observed here so I cannot comment, though I know this can be a problem with cowpea under dense cereal stands in West Africa.

El Mohamane

The seed is the input by which, at present, the small farmer can benefit from the scientific advancement at the least cost. Unfortunately many farmers are still expecting seeds of high yielding varieties. This is because the breeders do not see to the outcome of the varieties they have developed, and improve them as much as possible on the fields. What is urgently required is that the breeders follow up the varieties to the farmer's level to give him all the guarantee that he needs.

Ryan

I raise this more as a puzzle to think over rather than a question. Why do many farmers in India shift from intercropping to sole cropping when they adopt high yielding varieties of sorghum? Perhaps it is to take advantage of sequential crop opportunities that shorter duration high yielding crops allow on deep Vertisols. Perhaps extension services are not used to extending intercrop technologies which Dr. Willey's work suggests have economic superiority over sole crop.

Willey

Whatever may be the reasons, intercropping does not eliminate advantages with high yielding cultivars. One other factor that further complicates is that in India hybrids are often associated with high inputs, and there is a belief that under high inputs use, intercropping does not give worthwhile advantages. There are many studies on this in recent years, it is true that the relative advantage may be less with higher inputs. If one gets a 40-50% advantage under stress, only 20-30% may be obtained with high inputs, but the point is that 20% of 4000 kg at high inputs is a great deal higher than 40% of 500 kg at low inputs in terms of actual yields or returns.

Gunasekera

There is work in India indicating that farmers not only maximized income, but minimized variability. It may not be the best model on which farmer behavior could be explained but explanation along these lines may be needed. I invite comments from African scientists on this aspect. Have farmers given up intercropping in Africa under high input use as in India?

Nicou

In today's meeting, the intercropping systems (intercropping, sequential cropping, etc.) have been much discussed. But we have forgotten that much monocropping is still carried out in West Africa and especially in Sahelian regions of 400 to 600 mm rainfall. The farmer practices relay cropping only when he sows cowpea a month before the millet harvesting. This is done in order to exhaust the water reserves which remain in the soil. We have the impression that we know all about cropping techniques and even about sorghum fertilization. No one has commented on Dr. Clegg's paper. It summarizes the general impression which results from this symposium. We think that all problems can be solved through varieties resistant to everything and intercropping which enables the cereal to take up the nitrogen from the legumes (which has not been demonstrated). But we forget that if one makes a plant more productive, it consumes more of the soil resources and thus impoverishes the soil. It is known already that Sahelian soils are poor. If we want to produce more without wishing to give more inputs, we are heading in the long run towards an impoverishment of the environment. When the soil is so poor that sorghum does not grow well, I do not think that we can increase the production through miracle varieties, without utilizing the essential good agronomic techniques.

Stoop

I would like to add a little to what Dr. Nicou has said. The West African soils are very poor in fertility and have a low cation exchange capacity (<7 m eq/100 g soil). Research by IRAT and at Samaru have shown that the regular application of chemical fertilizers decreased soil pH to a critical level where crop production was seriously affected. Scientists must be aware of this problem in view of frequent suggestions during this workshop about fertilizer use for higher yields in Africa. Correction is particularly a problem because of the nonavailability of lime in most of the West African countries.

Niangando Oumer

Our experience with groundnuts showed that excessive fertilization deteriorates the soils. In traditional agriculture, a balance was maintained while our modern techniques are destroying this balance. Traditional techniques contribute to the buildup of soil resources. We tend to forget the importance of crop residues in the soil which the traditional techniques conserve.

Webster

It is very important in order to improve the life of the peasant farmer to first study his farming practices and constraints. Then one will be in a position to make suggested changes.

Singh

In the All India Coordinated Sorghum Improvement Project we have observed that if the traditional long-duration cultivars in the *kharif* season are changed to 90-95-day maturity cultivars, we can go for double cropping of Vertisols by growing safflower or chickpea in the postrainy season instead of single cropping as practiced at present. The possibilities of harvesting *kharif* sorghum at physiological maturity can alleviate the problem of seeding the second crop.

Willey

I agree that early maturing genotypes and harvesting at physiological maturity are important concepts that can increase the probability of taking a second crop. In practice of course there often has to be a compromise between these factors and problems (e.g., head molds and wet conditions) associated with early harvesting.

Tarhalkar

In a sorghum-groundnut intercropping system, sorghum is usually the dominant crop and groundnut suffers from sorghum competition. In your opinion, what are the ways of improving the groundnut yields?

Willey

If a full sorghum yield is required, competition on the groundnut can only be reduced to a certain extent, e.g., by widening or pairing of sorghum rows. Where a partial sorghum yield is acceptable, groundnuts seem remarkably able to produce a good yield without suffering too much competition.

Parvatikar

Intercropping in winter sorghums has not been touched by Dr. Willey, although Dr. Vidyabhushanam has said that chickpea has been tried. In Karnataka pigeonpea, chickpea, safflower and other *rabi* crops are being tried.

Willey

In general, research on intercropping on stored soil moisture during the postrainy season suggests a rather lower advantage than that obtained from many rainy season situations. But that lower advantage may still be useful; for example, we have found an advantage of about 15-20% with sorghum/chickpea. It is of interest that the less frequent occurrence of intercropping in the postrainy season and its lower advantages are usually attributed to a more stable environmental condition that is not dependent on rainfall.

Umat

What is an ideal cropping system with sorghum for a poor farmer working with marginal soils under low rainfall?

Willey

It is difficult to answer this satisfactorily without more information of the situation to which you are referring, but it sounds as if an ideal system would be sorghum with a hardy, drought tolerant intercrop. If there is usually a little residual moisture left after the sorghum harvest, the ideal intercrop would be pigeonpea, otherwise an earlier maturing cowpea might be better.

Dusseini

Density of millet and groundnut affects the yield of each crop in intercropping; the bigger the gap, the worse is the yield. What is your experience regarding yield of the above crops in sole and intercropping?

Willey

Millet/groundnut Intercropping at 1 millet: 3 groundnut row arrangement has been found to give about 50% of sole millet yield and 75% sole groundnut yield; this produces an intercropping advantage of 25%. The yield proportion however, can vary depending on the relative proportion of the component crops. Millet has a wide yield-population plateau and as such its yield may not be affected by small changes in plant population. But gaps in groundnut definitely affects its performance and can reduce the overall intercropping advantage.

Singh

I wish to make a comment on biological nitrogen fixation that Dr. Clegg has referred to in his presentation. The tests conducted at several locations in the All India Coordinated Sorghum Improvement Project indicate that *Azospirillum* is more efficient than *Azotobacter* in fixing nitrogen. In the rainy season there was fixation of nitrogen ranging from 20 to 40 kg N/ha. However, this effect was not observed in the postrainy season probably due to the lack of sufficient moisture.

Another kind of biological nitrogen fixation is through legumes in intercropping. At the Indian Agricultural Research Institute, New Delhi, we observed that fodder cowpea would benefit sorghum in intercropping in the same season and also leave residual benefit to the following wheat crop. The residual benefit from peanut or intercropped cowpea was equivalent to 40 kg N/ha. However, no such effects were observed with soybean.

Session 7

Food Quality and Utilization

Chairman: L Munck

Co-Chairman: J. F. Scheuring

Rapporteurs: D. S. Murty

V. Subramanian

Sorghum Dry Milling

R. D. Reichert*

In many developing countries sorghum grain is traditionally processed by the very laborious and time-consuming mortar and pestle pounding method. This process was partially mechanized by the introduction of small grinders in many villages. The trend recently has been toward the construction of larger, centralized facilities which have the capability of cleaning, dehulling and grinding of grain. By the year 2000 it has been estimated (Miche et al. 1980) that if only 20 to 40% of all sorghum produced is processed, some 1000 -8000 medium capacity industrial plants (3500 tonnes/yr) would be required in Africa. During the last 10 years a great deal of activity has been focused on the development of these village and industrial-scale systems, particularly in countries in Africa. Development agencies such as the FAO and IDRC. government institutions, universities and especially private industry have been very actively involved in this area.

Sorghum grain is processed to remove the fibrous and often highly colored pericarp and testa layers and to reduce the remainder of the seed to flour. Often the peripheral layers also contain anti-nutritional constituents such as tannins. In the traditional mortar and pestle method, and most of the mechanical methods, much of the germ is often retained with the endosperm.

Efficient mechanical dehulling of sorghum has been one of the major problems in the development of sorghum processing facilities and this is an area where most sorghum milling research has been concentrated in the last 5-10 years. The various technologies which have been used to dehull sorghum (or could potentially be used) have been categorized and include: (a) roller-milling equipment and peeling rolls, (b) rice-dehulling equipment, (c) abrasive-type dehullers, and (d) attrition-type dehullers. Many of the machines in the last two categories have been developed specifically for sorghum and similar grains. Approximately 40 dehullers or dehulling methods are reviewed in this paper, the majority (22) being abrasive- or attrition-types. The main objective is to record the major principle of operation of each dehuller (as far as this information is available) and its application to sorghum or a similar cereal. Several commercial- or pilot-scale mills in Africa, most of which have been erected within the last decade are also described. Also discussed is the development of equipment for predicting the milling quality of plant breeders' samples.

Since private industry is actively involved in sorghum milling research, much of this information was obtained from unusual sources (advertising bulletins, annual reports, proceedings and internal reports). Hence, some of the information is incomplete. Undoubtedly, some dehulling or mill systems have been overlooked. Other aspects of dry milling not covered here (e.g., grain grinding, air classification, degermination, milling products and utilization) have been amply described by others (Hulse et al. 1980; Hahn 1970).

Dehulling Equipment for Sorghum

Application of Roller-Milling Equipment or Peeling Rolls

The first attempts to dry mill sorghum were made on wheat-milling machinery because of the ready availability of the equipment and the expertise of the individuals involved. Investigators have used the Buhler mill (Badi et al. 1976; Jones and Beckwith 1970; John and Muller 1973; Shepherd and Woodhead 1969-70; Perten 1977b; Ander-

* National Research Council of Canada, Prairie Regional Laboratory, Saskatoon, Saskatchewan, Canada. NRCC Paper No. 19711.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru, A.P., India. Patancheru. A.P. India: ICRISAT.

son 1969; Shepherd et al. 1970-71), conventional roller-milling equipment (Hahn 1969; Crawford et al. 1942; Goldberg et al. 1946; Shoup et al. 1970a), the Miag Multomat experimental flour mill (Shoup et al. 1970b), Brabender Quadrumat Sr. and Jr. mills (Rooney and Sullins 1970; Maxson et al. 1971; Badi et al. 1976), the Maxima mill (Raymond et al. 1954), and a wheat semolina mill (Pilon et al. 1977). The general consensus appears to be that roller milling is not very appropriate for sorghum because the product does not have consumer acceptability (for example, in Senegal, Chad and Sudan) and because production costs are relatively high due to a low extraction rate (Perten 1977b). The gray color and speckiness of the flours also limit the usefulness of roller milling (Hahn 1969, 1970)

An abrasive, peeling roll was developed by Shoup et al. (1970b) to dehull tempered sorghum. A yield of up to 89% of peeled grain was obtained, which is probably close to the maximum possible yield. Weinecke and Montgomery (1965) have used the same principle. The Tropical Products Institute, London, has recently developed and tested a sorghum peeler in Sudan (D.A.V. Dendy, personal communication). The SOTRAMIL process uses abrasive rolls to obtain extraction rates of 65-75% (millet) after hammer milling (Adrian et al. 1975). In the SEPIAL process, conditioned grains are peeled by the action of paddles in an apparatus with a vertical axis. Then by vigorous rubbing in a brushing machine a protein-rich fraction (aleurone plus adjacent layers) and decorticated grain is produced (Adrian et al. 1975). The latter two processes have mainly been applied to millet.

Application of Rice-Milling Equipment

Since rice dehullers and polishers have been used on rice for many years, a detailed description of the principle of operation of these machines is available elsewhere (Borasio and Gariboldi 1979).

The Ce Co Co dehuller (Ce Co Co, Chuo Boeki Goshi Kaisha, P.O. Box 8, Ibaraki, Osaka 567, Japan) has been used to dehull tempered sorghum in the National Research Council of Canada, NRCC, integrated milling process (Anderson and Burbridge 1971; Anderson et al. 1977). Shepherd et al. (1970-71) and Kapasi-Kakama (1977) also used the Ce Co Co to dehull sorghum successfully. Three models of the machine are available with throughputs of 420-840 kg per hour of sorghum and power requirements of 5-10 hp.

Viraktamath et al. (1971) tested three types of rice-milling equipment: a rice huller (a horizontal ribbed rotor), a Gota machine (a horizontal truncated cone), and a Dandekar-type rice mill (a vertical inverted truncated cone rice polisher). Only the latter produced satisfactorily dehulled sorghum from the tempered grain.

A Squiers rice huller, consisting of a solid-cast rotor with several bars surrounded by a screen provides abrasive action as the grains rub against the rotor, screen, and one another. Anderson et al. (1969) used this dehuller on tempered sorghum followed by impact milling and sieving.

A Satake rice whitening machine (Satake Engineering Co., Ltd., Tokyo, Japan) has been tested by Robinson Reunert Ltd., Thora Crescent, Wynberg, Sandton 2199, South Africa and good results were apparently obtained (personal communication).

An Engleberg rice huller or similar dehullers have been tested (Raghavendra Rao and Desikachar 1964) and are used in several West African countries (e.g., Ouagadougou, Upper Volta and Bamako, Mali). The machine consists of a ribbed rotor rotating within a slotted screen.

In general, many of the rice dehullers, particularly those like the Engleberg type do not work well on sorghum probably because it is much softer than rice. Private industry and others have therefore resorted to the development of other types of dehullers, especially the abrasive- and attrition-types.

Abrasive-type Dehullers

Abrasion-milling employs carborundum or other abrasive surfaces mounted on a vertical or horizontal rotor to progressively abrade the outer layers of the grain. Some of the rice dehullers mentioned in the last section also operate on this principle.

Bavaria Record

Etablissements Rohr (11, rue Jacques-Duclos B.P. 19, 95204 Sarcelles CEDEX) distributes three types of Bavaria Record machines. The dehuller-scourer type is sold in eight models (A to H) With machine lengths varying from 110 to 227 cm. The weight varies from 230 to 500 kg, with throughputs (on wheat) from about 450 kg/hr for the smallest model to about 1800 kg/hr. In these machines, abrasive elements are mounted horizontally on an axis and these function to remove hull and beard particles from rye, wheat, etc. A brush-type machine is available in four models (A to D) and operates like the dehuller-scourer. The abrasive-elements are replaced by a brush-type cylinder mounted on a horizontal shaft. Machine weights vary from 175 to 230 kg and throughputs range from 600 to 2000 kg/hr. A combined dehuller-brush type machine has both abrasive elements (2/3) and brush-type cylinders (1/3) mounted on a horizontal rotor.

Wondergrain Jaybee

The abrasive action of the Wondergrain Jaybee dehuller (Jaybee Engineering Pty, Ltd.. 227 Princes Highway, Mail Box 168, Dandenong, Victoria 3175, Australia) is provided by four metal disks with abrasive material glued to both faces (Fig. 1). These disks rotate at 2940 rpm on a horizontal shaft within an octagonal basket made from a metal screen. The basket rotates at an approximate speed of 20 rpm in the direction opposite to that of the disks. Fines pass through the metal screen of the basket and are aspirated into a cyclone. A belt of compressed air keeps the holes in the screen clear of fines. The front panel of the basket serves as the door for exiting grains.

The machine is used on a batch basis. Munier (1980) found that with wheat, as the load was increased from 12 to 20 kg, the yield decreased from 80.7 to 61.8% after 3 min of dehulling. When the retention time of a 12 kg sample was varied from 30 sec to 2 min 30 sec, the yield decreased from 95 to 76%.

FAO (Fondateur de l'atelier de l'Quest) Eurafric M-164

The abrasive action of the FAO Eurafric dehuller (distributed by Societe Comia-Fao S.A., 27, Bd de Chateaubriant, 35500 Vitre, France) is provided by a rubber cone rotating within an emery coated enclosure (Fig. 2). The distance between the cone and the emery surface is variable and depends on the size of the grain. Following dehulling, the light bran and dust are removed by a screening apparatus. The larger bran particles are removed by air aspiration.

The major variable affecting the degree of dehulling is the number of times the grain is passed through the machine. The distance between the cone and the abrasive surface seems to be of secondary importance. After six passes. Munier (1980) found that the yield of wheat was 66.7%. For millet, using three passes the throughput was in the order of 150 kg/hr.

Decomatic

The abrasive action of the Decomatic dehuller (Fig. 3) manufactured by Bernhard Keller AG, Herostrasse 9, CH-8048 Zurich, Switzerland, is provided by five polishing disks mounted on a vertical rotor (G). Grain flows from the glass cylinder over a cone (A) which distributes the grain evenly into the decortication space. The polishing disks (E) rotate within a cylinder of perforated sheet-metal (C). Two decortication cylinders (D) are located lengthwise to the metal cylinder providing a mechanism whereby the degree of decortication can be adjusted. To separate the fines from the dehulled grains, a strong current of air enters at (B) and blows the fines through the screen and finally into the air exit (J) and to the ventilator. All around the millstones, at the base of the screen, there are several segment-like sliding valves which are adjustable from the outside by micrometer screws (F). This adjustment regulates the throughput. Following decortication, grains leave the machine through the discharge channel (L). The machine is driven by a 20 hp electric motor (H) through a V-belt drive (K). The machine dehulls a variety of cereals and legumes and Munier (1980) reported that 47 machines had been installed in five countries.

Perten et al. (1978) tested the Decomatic on sorghum and found a negative, linear relationship between the throughput (kg/hr) plotted on a log scale and the decortication rate. Throughputs were decreased at lower rotor speeds. The number of broken kernels increased linearly with the decortication rate. At lower rotor speeds, the number of broken kernels was dramatically reduced. The rapid reduction of fat, ash, and protein content at low rotor speeds suggested that the peripheral layers of the seed (germ, pericarp, aleurone layer) were removed more efficiently than at high rotor speeds. Most of the relationships found by Perten et al. (1978) are probably applicable to a variety of abrasive-type dehullers.

Vertical Shelling Machine Type-270

This dehuller (Fig. 4) manufactured by F. H. Schule

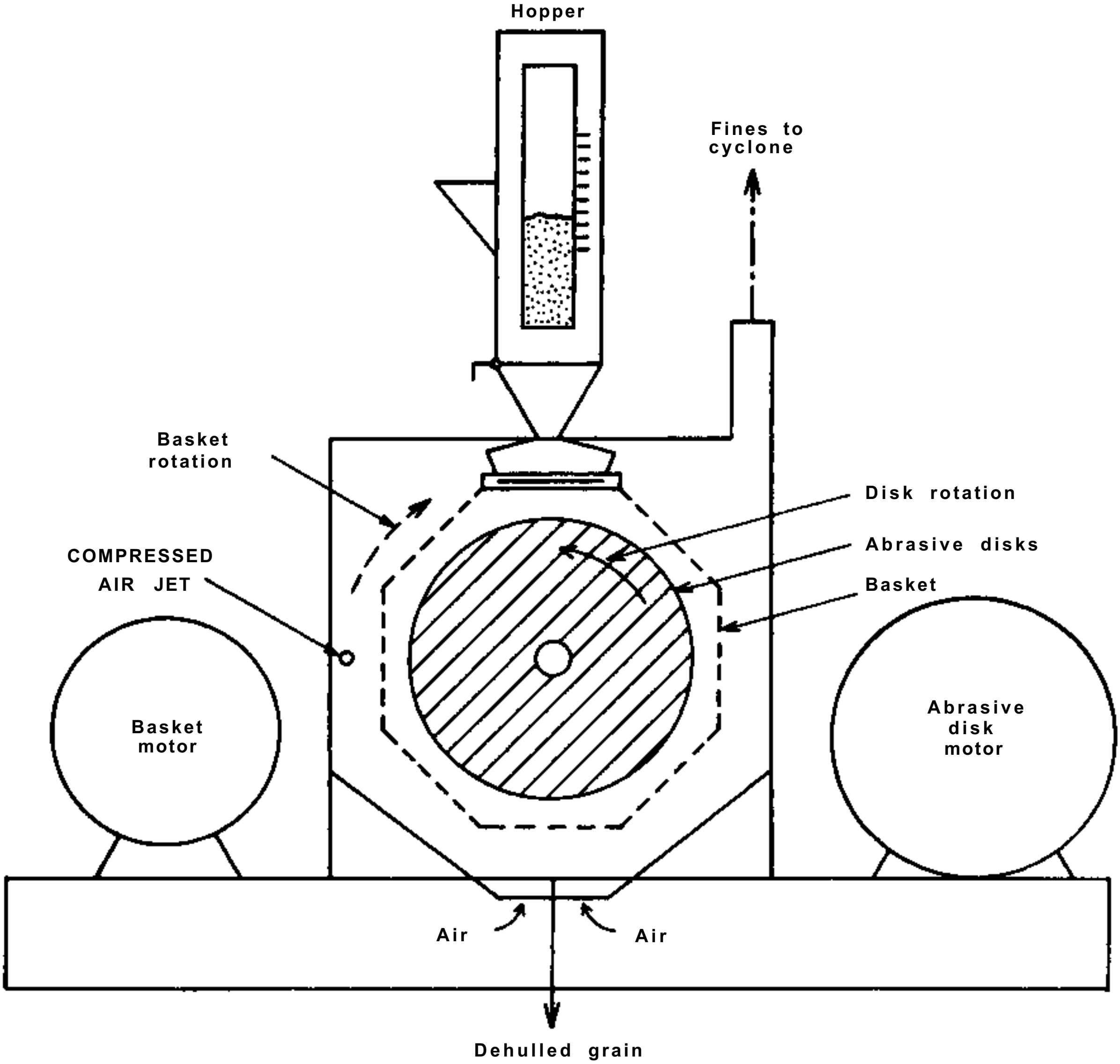


Figure 1. Schematic diagram of the Wondergrain Jaybee dehuller. (Adapted form Munier 1980.)

GMBH, D-2000 Hamburg 26, West Germany is similar in principle to the Decomatic. Seven emery disks (B), one tapered and six cylindrical, rotate on a vertical shaft. The granulation of the discs becomes finer from top to bottom. When the feed gate (A) is opened, grain enters the working chamber, where the disks (B) provide the abrasive action necessary to gradually abrade the seeds. Throughput is regulated by an adjustable discharge gate (E). A fan (D) draws air through the hollow shaft from the top of the machine. This air passes through the spaces between the emery disks and through the material being dehulled, carrying with it fine particles. The fine particles are carried through the perforations of a cylindrical metal screen (C), into a separation chamber (F) and are finally removed via a discharge pipe (G). The manufacturer claims a throughput of a 200 -1800 kg of sorghum per hour. A 25-hp electric motor drives the machine which weighs 1125 kg.

PRL, PRL/RIIC and PRL Mini Dehullers

The PRL dehuller manufactured by Nutana Machine Co., Saskatoon, Canada, and Ackroyd Construction Ltd., Toronto, Canada, resulted from

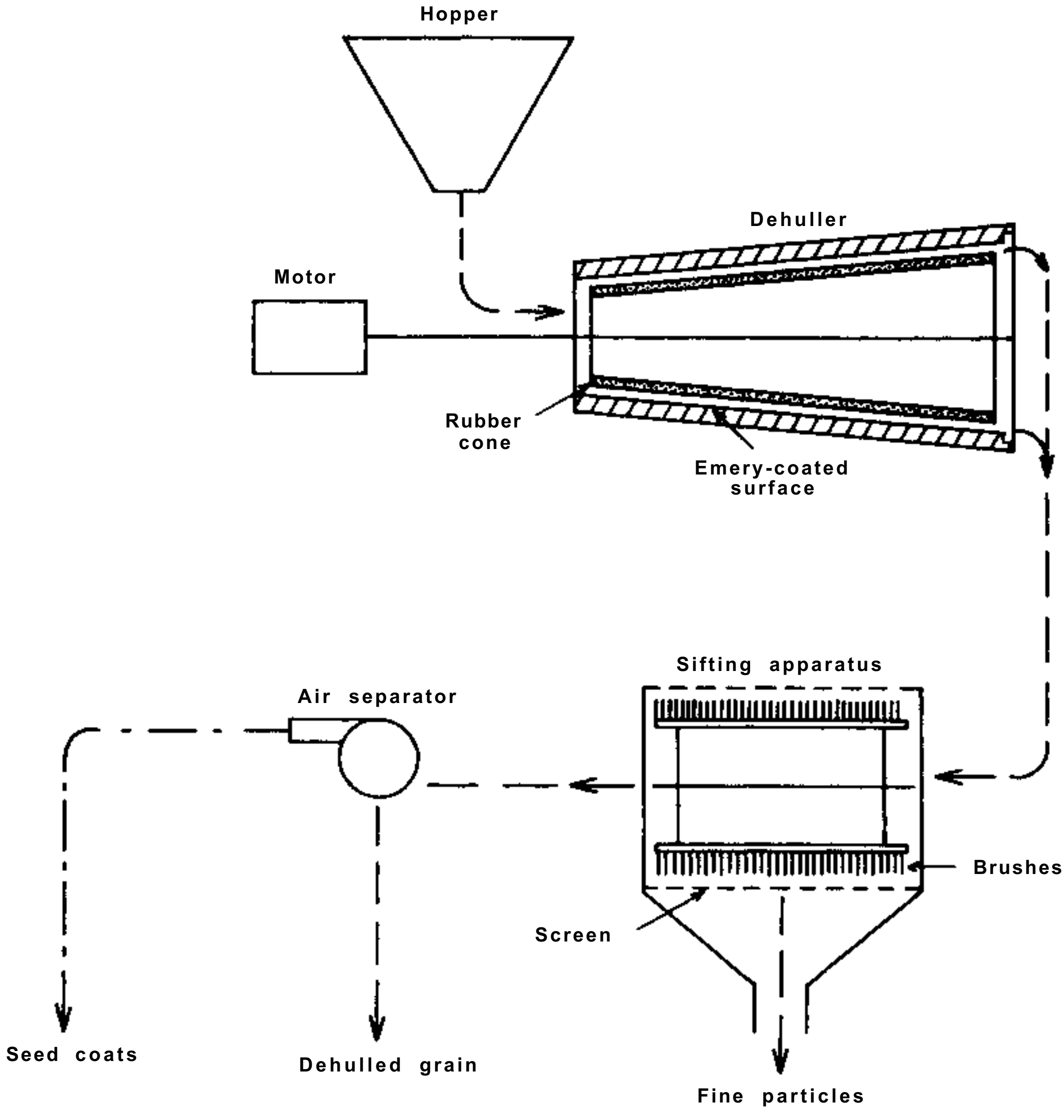


Figure 2. Schematic diagram of the FAO Eurafric dehuller. (Adapted from Munier 1980.)

extensive modification of the George Hill grain thresher (Reichert 1977). The abrasive action is provided by 13 carborundum stones (30.5 cm in diameter x 3.2 cm thick) or 27 resinoid disks (30.5 cm in diameter x 0.64 cm thick) mounted on a horizontal axis (Fig. 5). When the feed gate is opened, grain flows from the hopper into the body of the machine. Fines generated by the action of the abrasive surface are taken off by the fan and are eventually bagged at a cyclone. Dehulled grain exits via an overflow outlet. Throughput is adjusted by regulating the feed gate and the adjustable gate on the overflow outlet. Throughputs with sorghum were about 300 and 550 kg/hr at extraction rates of 70 and 85%, respectively, when a stone speed of 1050 rpm was used (Reichert and Youngs 1976). Using a softer sorghum, throughputs in the order of 900 kg/hr were obtained with a stone speed of 1300 rpm and an extraction rate of 72% (Oomah et al. 1981a).

The PRL dehuller was modified at the Rural Industries Innovation Centre (RIIC) in Botswana to process grain in either a continuous or batch operation. The modified machine (PRL/RIIC) is presently manufactured by RIIC, Nutana Machine Co. and Ackroyd Construction Ltd. The PRL/RIIC dehuller has a hinged door at the bottom of the

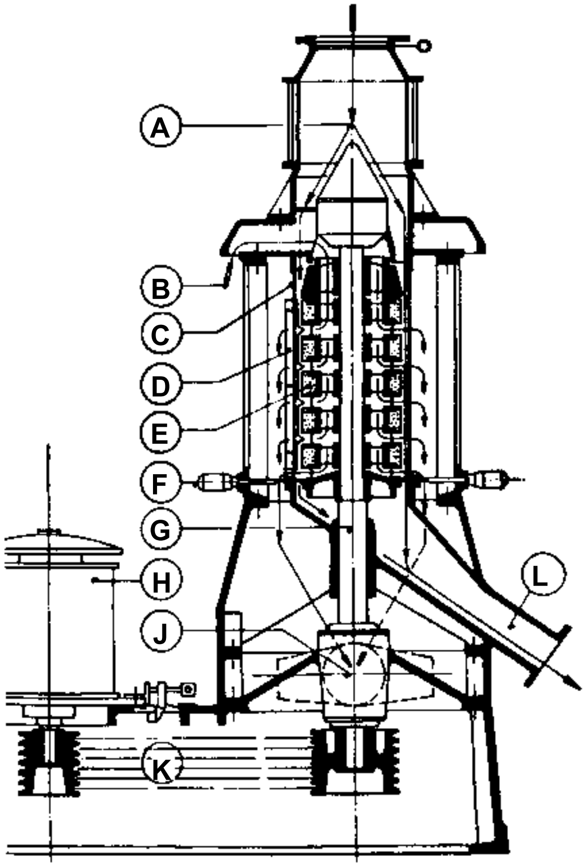


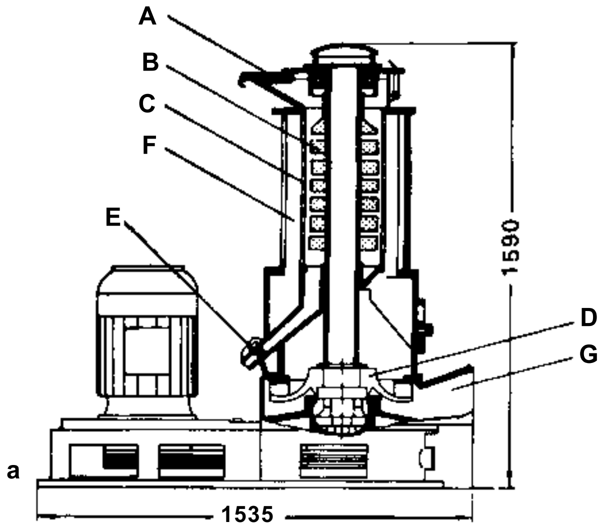
Figure 3 .Schematic diagram of the Decomatic dehuller. (Bernhard Keller AG literature.)

machine, which is used during batch operation to release the dehulled grain. The dehuller is similar to, but smaller (30.0 x 63.5 cm) than the PRL dehuller and contains 13 carborundum stones (25.4 cm in diameter x 1.9 cm thick). When operated continuously under field conditions the machine can process up to 3000 kg in 8 hr.

The PRL mini dehuller, also available from Nutana Machine Co., is operated on a 7-kg batch basis (Fig. 6). It is useful in a laboratory situation or in a village setting where it performs a service function. Carborundum stones or resinoid disks (25.4 cm in diameter) provide the abrasive action. Grain is simply loaded into the machine, the cover plate (A) is locked, and the disks (B) or stones are rotated at 1500-2000 rpm for 1-5 min. The dehulled grain plus bran are dumped into the emptying chute (C) by rolling over the body of the machine and unlocking the cover plate. Grain and bran are subsequently separated using either air or a sifter. The machine requires a 4-hp motor. It has been successfully applied to cereal grains and grain legumes (Oomah et al. 1982).

UMS Dehuller Type DVA

This dehuller, distributed by United Milling Systems, 8 Gamle Carlsberg VEJ, DK-2500 Valby, Copenhagen, Denmark, provides an abrasive effect by the action of double-edged, interchangeable knives (E) mounted on a vertical rotor (Fig. 7).



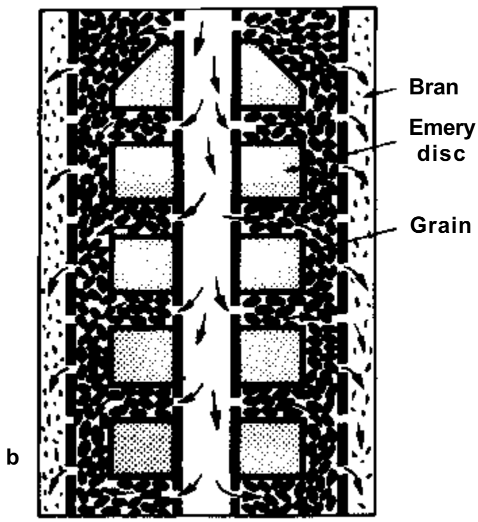


Figure 4. (a) Schematic diagram of the Vertical shelling type 270 machine (dimensions in mm); (b) magnified view of the working chamber illustrating the air and bran flow. (F.H. Schule GMBH literature.)

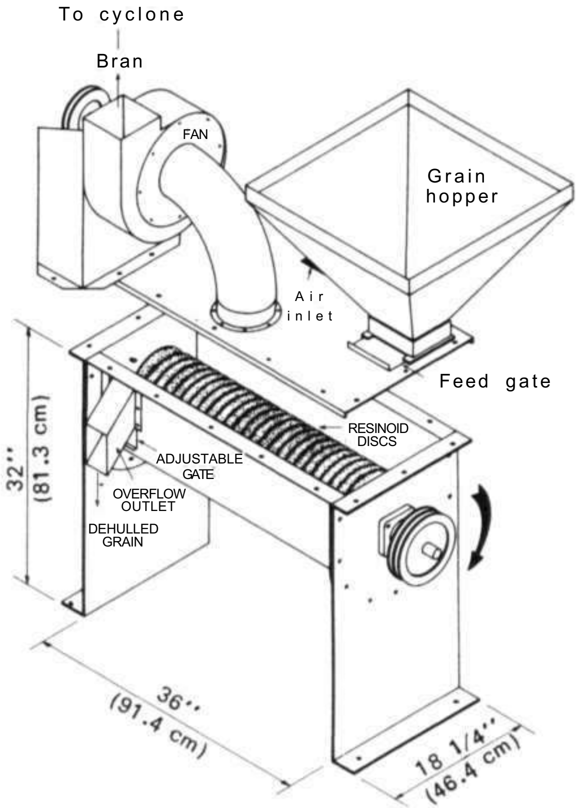


Figure 5. Schematic diagram of the PRL dehuller.

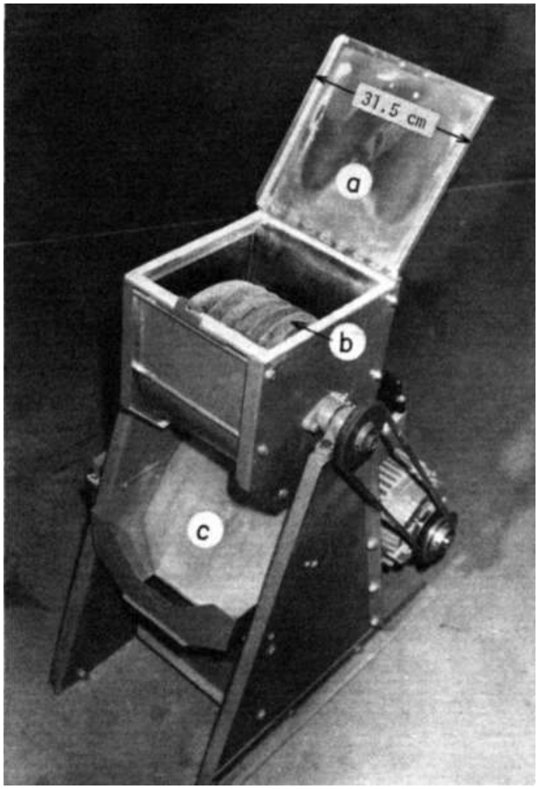


Figure 6. Photograph of the PRL mini dehuller.

Grain enters the machine at (A) and a vertical screw conveyor (C), attached to the lower part of the rotor (B), moves the grain upward into the dehulling chamber (D). The distance between the knives, mounted in the upper part of the rotor, and a stationary perforated cylindrical screen (F) determines the rate of dehulling. Fines are blown through the screen, while the dehulled grains are taken off at the top outlet gate (H). The throughput is regulated by means of counterweights (G) attached to the outlet gate (H). The manufacturer claims a throughput of up to 2000 kg/hr of sorghum. The machine is powered by a 30 hp motor and weighs 447 kg.

Palyi-Hansen BR 001-2

This unit consists of a multiple combination of rotating disks, each one consisting of a side with abrasive corrugated blades and a side having perforated abrasive blades with openings (Rasper 1977). The disks are mounted on a horizontal shaft and are hollow to enable the air to flow under pressure through the perforations in the abrasive surface. The disks are housed in a perforated metal drum through which pieces of bran are blown. Rasper (1977) reported that the machine was in the early stages of testing and, to date, the progress of its development is not known.

Buhler-Miag Types DNRH, DSRD, MHV, DSRH, MKDA

Buhler-Miag (9240 Uzwil, Switzerland) is involved in the problem of dehulling sorghum (Wyss 1977). However, very little information is available on the application of the five abrasive-type dehullers they manufacture.

The horizontal hulling machine (type DNRH) provides abrasive action with emery rings in a fixed sieve-plate cylinder mounted on a horizontal axis. A 15 hp motor gives throughputs ranging from 250 to 1000 kg/hr at rotor speeds between 800 and 1600 rpm. The machine is used mainly on

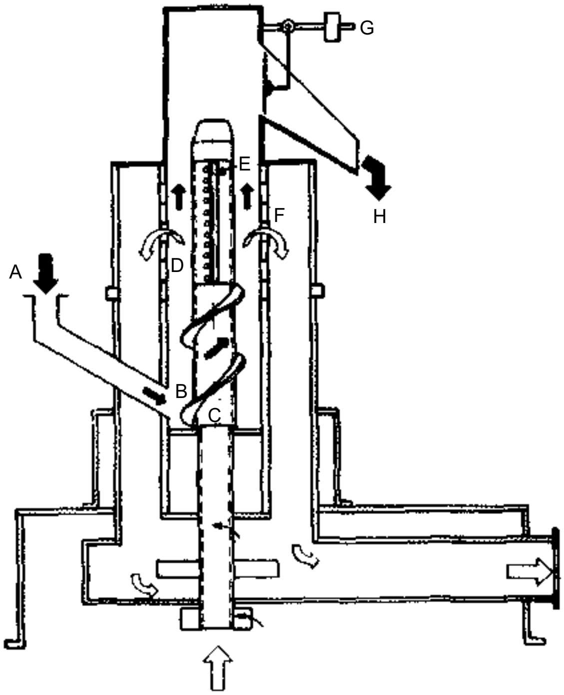


Figure 7. Schematic diagram of the UMS dehuller type DVA. (United Milling Systems literature.)

barley, although other cereals and legumes can also be denuded.

In principle, the vertical whitener-pearler machine (type DSRD) is similar to the Vertical shelling machine type 270 (Fig. 4) but the construction is somewhat different. The machine has been used for whitening of brown rice and for dehulling leguminous seeds, barley, and kiln-dried whole oat groats.

In appearance and dimensions, the Decortiqueuse (type MHV) is very similar to the Decomatic (Fig. 3). Five emery wheels provide the abrasive action.

The polisher (type DSRH) is used for intensive pearling or polishing, particularly of rice. A special rotor mounted on a horizontal shaft within a hexagonal mantle provides the abrasive action.

A rotor with special disks provides abrasive action to dehull corn in the Decortiqueuse a mais model MKDA.

Strong-Scott Series 235 Huller

This dehuller manufactured by Sullivan Strong-Scott Ltd., P.O. Box 872, Winnipeg, Canada, contains a series of horizontally-mounted abrasive wheels. Both feed and discharge are controlled to determine the degree of dehulling. Bulgur, pot barley and pearl barley are commonly produced with this machine.

Attrition-type Dehullers

The term attrition dehulling is generally applied to a mill in which the dehulling takes place between two disks of steel or stone rotating in a horizontal *or* vertical plane (similar to a plate mill). One of the disks may be stationary and either of the disks may be modified with a variety of impact or cutting surfaces.

Palyi Compact Mill

This machine, originally distributed by United Milling Systems, provides the dehulling action by two attrition plates (one stationary and one fixed) fitted with saw-tooth blades (Fig. 8). The distance between the plates is adjustable providing variable extraction rates. After the grains leave the plates, they pass into a cylindrical head where a drum rubs the grains against a. cylindrical metal screen. By adjusting the distance between the cover plate and the extended edges of the metal screen, it is possible to vary the retention time in the head. The dehuller is powered by a 7.5-hp electric motor. Fines pass through the screen, de Man et al. (1973) tested the machine and modifications of it, and obtained excellent results on sorghum and millet. However, Reichert and Youngs (1976) found that the throughput was relatively low (70 and 140 kg/hr at extraction rates of 68 and 83%, respectively) and that the dehulling efficiency was relatively poor.

UMS Dehuller Type DHA 400 and 600

United Milling Systems now distributes larger-scale and improved versions of the Palyi compact mill. The DHA 400 and 600 operate on 15 and 30-hp motors, and the manufacturer claims throughputs of 800 and 1400 kg/hr, respectively. Extraction rates were not specified.

Comparative Studies

Perten et al. (1974) reported on a collaborative study of dehulling and grinding equipment for sorghum and millet which was carried out be-

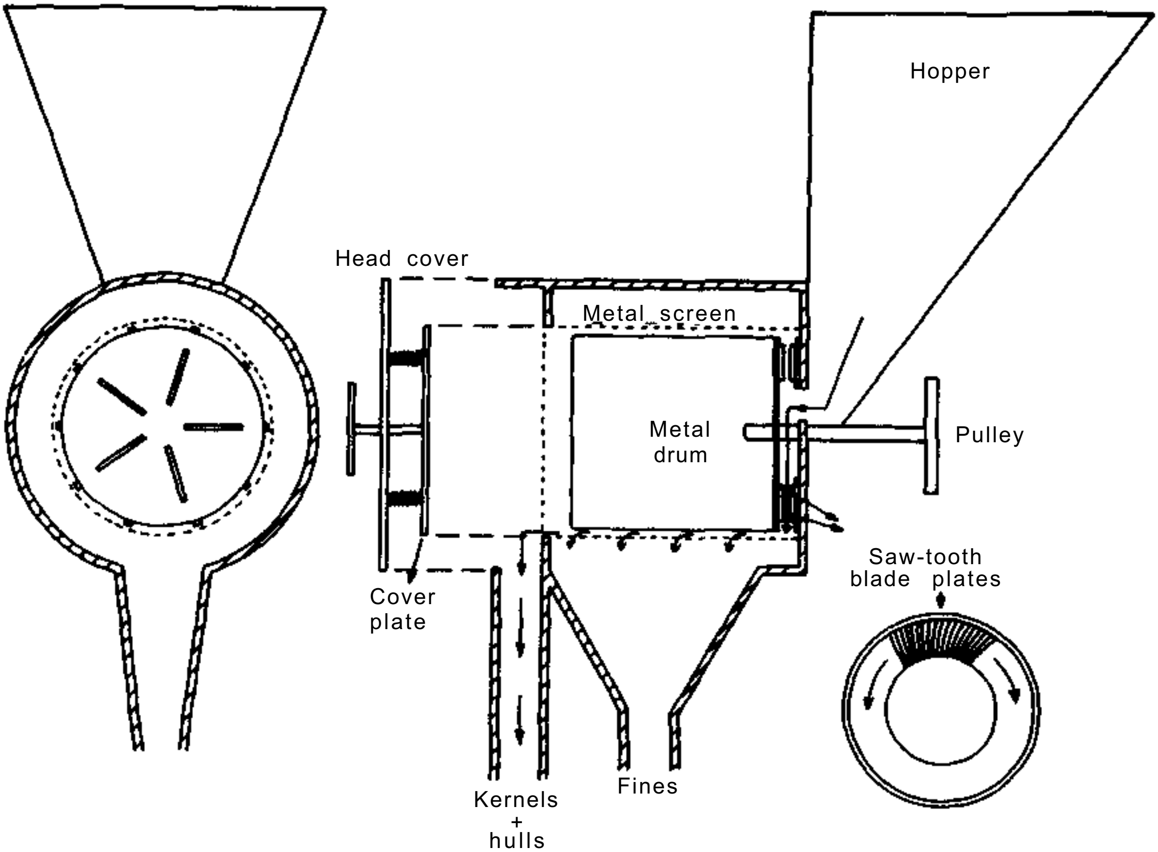


Figure 8. Schematic diagram of the front view (left) and side view (right) of the Palyi compact mill. (Reichert and Youngs 1976.)

tween 12 laboratories or manufacturers of milling equipment in 10 countries. Participants were sent up to 50 kg of grain and were asked: (a) to dehull the grain to an extraction between 75 and 80%, (b) to report methods and equipment used, and (c) to submit a sample of dehulled grain. The results of those participants who met these requirements are given in Table 1. Criteria used for choosing the best dehuller included throughput and equipment considerations, power consumption, cost, kernel cracking, purity judged mainly by ash. fat and fiber content, and color. The best results with respect to purity were obtained with the Vertical shelling machine type 270 and the Decomatic. The latter was chosen for installation in the FAO/FRC pilot flour mill in the Sudan, which is described later in this paper.

Reichert and Youngs (1976) demonstrated quantitatively, using a red pericarped sorghum variety, that abrasive-type denuding in an industrial carborundum-stone dehuller (Hill grain thresher-HGT) and a laboratory barley pearler (Strong-Scott-SS) was more efficient than attrition-type dehulling (Palyi Compact mill-PCM). Sorghum was progressively dehulled with all machines. Color measurements of the flour (indicative of pericarp removal) were used as a criterion for judging efficiency (Fig. 9). To produce flour which was comparable in color to a traditionally processed product, 21 and 23% of the kernel was removed with the SS and HGT, respectively, while 44% was removed with the PCM. An excessive amount of kernel cracking with the attrition-type dehuller was one explanation. Another was that the sharp saw-tooth blades of the latter dug deeper into the seeds and removed relatively more of the endosperm. Throughput, kernel cracking, equipment considerations, and chemical composition of the dehulled grain (Reichert and Youngs 1977) were also used to compare the dehullers.

In a similar manner, using an Agtron spec-

Table 1. Comparison of six dehulling units on sorghum grain (Perten at al. 1974).

Dehuller	Extraction rate (%)	Kernel cracking' (%)	Color[b]	Chemical composition			
				Ash (%)	Protein (%)	Fat (%)	Fiber (%)
Eurafric M-164	80	54	>37	1.2	12.9	2.9	0.9
Buhler-Miag prototype	75	15	>37	1.3	13.0	2.7	0.9
Decomatic	76	24	>37	1.1	12.8	2.6	0.7
Vertical shelling machine type 270	80	8	35.1	0.9	11.6	1.9	0.4
Palyi Compact mill	78	41	>37	1.1	13.0	3.1	1.1
Speaf	76	10	>37	1.4	12.6	2.8	1.3
Whole sorghum	—	—	>37	1.7	12.8	3.9	2.3

a. Weight percentage less than 2 mm.
b. Lower numbers represent lighter colors.

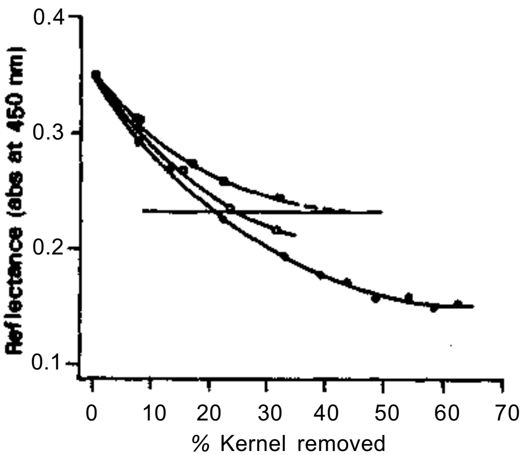


Figure 9. Comparative rate of flour color improvement (reflectance measurement at 450 nm) as a function of progressive dehulling with laboratory (●), commercial abrasive-type (□), and attrition-type dehullers (■). Horizontal line represents a traditionally acceptable flour. (Reichert and Youngs 1976.)

trophotometer to measure flour color, Oomah et al. (1981a) showed that the PRL dehuller equipped with resinoid disks and the PRL/RIIC dehuller equipped with fine-grit stones were more efficient than the HGT equipped with coarse-grit carborundum stones. To produce the same acceptable color, the yield was 12 to 15% lower with the HGT than with the PRL or PRL/RIIC dehuller.

Intermediate and Pilot Scale Sorghum Processing Facilities in Africa

The last 10 years have seen a proliferation of village and industrial-scale systems for processing sorghum grain. Countries in Africa have been the testing site for many of these developments.

Sotramil: Zinder, Niger

This mill, which has a capacity of 5400 tonnes per year, is equipped with a model-G Bavaria Record dehuller (approximately 1.1 tonne/hr) and one attrition-type Sepial wet (500 kg/hr) dehuller (Miche and Feillet 1980). Besides sorghum, wheat is also processed by simply grinding and sifting of the whole grain. The Sepial dehuller is apparently not functional and has been abandoned. At one time it had been used for fermented-millet flour production.

Sentenac Mill: Dakar, Senegal

This mill includes receiving, cleaning, dehulling, storage, and grinding equipment and has an hourly capacity of 2-3 tonnes (Miche and Feillet 1980). Dehulling is accomplished with a Wondergrain Jaybee dehuller operating on a batch basis. The mill processes wheat, maize, sorghum, millet, and dry legumes.

Somdiaa Mill: Bonfora, Upper Volta

This mill is also equipped with a Wondergrain Jaybee dehuller (Miche and Feillet 1980).

Maiduguri and Kaduna Mills: Nigeria

The Maiduguri mill, which began operation in 1973, has been extensively described in IDRC publications (Anon. 1976; Eastman 1980). A precleaner initially removes stones and other foreign matter from the grain. A PRL dehuller and a Jocobson pulverator are used to dehull and grind the grains, respectively. Most hammer and plate mills produced an acceptable flour, but the Jacobson model was found to be superior because it did not become clogged as did many other grinders. A flour sifter is included in the mill although it was found that simply changing the screens in the hammer mill produced an acceptable flour. Of the various sifters that were tested, a Kason Centri-Sifter was preferred because it has a relatively simple, horizontal, one-screen design. It produces only two fractions of flour whereas vertical sifters that are commonly used to sift wheat flour produce many more fractions and are unnecessarily complex.

The Kaduna mill is similar to the Maiduguri mill. However, two PRL dehullers are used for dehulling and another two are planned. Some of the equipment used in these mills, or similar equipment, is also in operation in Tanzania, Ghana, Senegal, and Sudan.

Pitsane, Kanye and Gabane Mills: Botswana

Forrest and Yaciuk (1980) have described the development and rationale of three types of milling systems, i.e., commercial milling, service milling, and service/commercial milling, which are being accomplished at Pitsane, Kanye and Gabane, respectively, in Botswana. The commerical mill at Pitsane was instigated in 1977 by the Botswana Agricultural Marketing Board with the assistance of the IDRC. Grain is purchased in bulk from farmers or from a depot and then dehulled (two PRL dehullers) and ground (Jacobsen model) in a continuous fashion. Four to five tonnes of good quality flour are produced per workday. The flour and bran fractions are weighed, packaged and sealed and transported to retail traders for sale to their customers. The daily capacity of the machinery is in the range of 2500 kg. The flour produced by the mill sold extremely well. However, the bran could not be absorbed by the region quickly enough. As a solution, a feed mill was erected in 1978 which incorporated the bran fraction into a packaged poultry feed.

The service mill at Kanye was established in 1979 by the Rural Industries Innovation Centre. RIIC, on the basis of a survey in the Pitsane area, which showed that most farmers preferred flour produced from their own sorghum. In this operation, customers bring grain to the mill (10-70 kg), the grain is dehulled and ground for a fee and then both flour and bran are returned to the customer. The mill is equipped with a PRL/RIIC dehuller, a grinder, a scale, and a motor. Neither a cleaner nor a sifter were required for the conditions in Botswana. Throughput of the mill, usually 1500 -3000 kg/day, is dependent upon the demand.

In late 1979, a second mill was established by RIIC at Gabane, which accomplished both service and commerical milling. The PRL/RIIC dehuller is operated on a continuous basis (commerical milling) from 8:30 a.m to 1:00 p.m. and on a batch basis in the afternoon to accomplish the service milling function. It has a capacity of approximately 1400 tonnes of grain per year operating on one 8 hour shift for 250 days per year. Very efficient use of manpower and equipment is attained using this system. A grinder, scale, and motor are also included in the mill.

In support of the sorghum milling industry the RIIC has developed a package for those interested in buying a mill, which is described in the booklet "The machine that dehulls and grinds sorghum for us" (Eisener et al. 1979). All equipment except the hammermill and engine are manufactured and supplied by RIIC in Botswana. The RIIC also provides a 3-week training session to familiarize mill owners and operators about the milling installation, mechanical, and business management skills. A film and the publication "An end to pounding" (Eastman 1980) describe the milling systems which are used in Maiduguri, Kaduna, Botswana, and elsewhere. In addition, information is provided on planning and evaluation of a mill including detailed cost estimates.

FAO/FRC Pilot Flour Mill: Khartoum, Sudan

The main objective of this mill is to demonstrate that imports of wheat, which are approximately

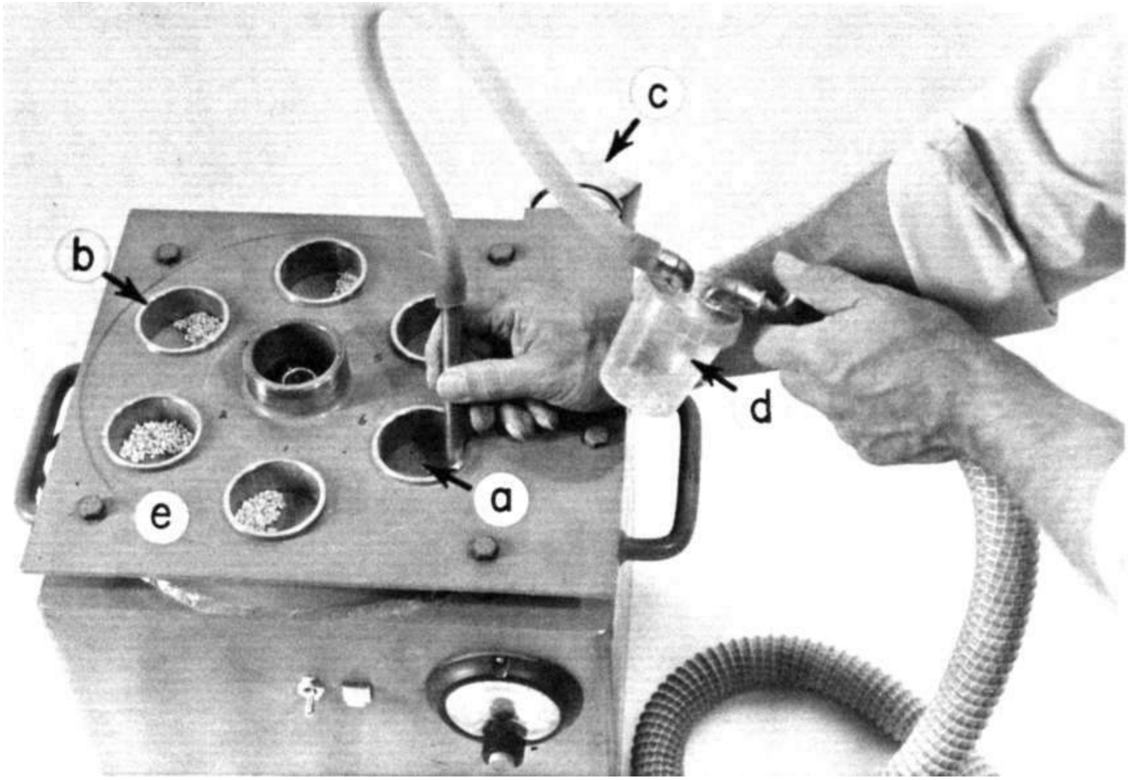


Figure 10. Photograph of the TADD used to predict dehulling quality. (*Oomah et al. 1981.*)

the abrasive ring (c) positioned on the periphery of the chamber. Fines are blown through a perforated metal screen (d) and into the collector (e). After removing the screen, dehulled grain is blown into a second collector. Impeller blade speed, which can be controlled (f), number of blades, and surface grit size of the abrasive ring affect the decortication (Shepherd 1981a). Shepherd (1981b) has used staining techniques to determine the degree of decortication.

Conclusions

The need for mechanical processing systems to replace traditional hand pounding methods has led to much activity in this area in the last 10 years. Much of the research has concentrated on the development of suitable dehulling equipment for sorghum, since other aspects of milling this grain (cleaning, grinding, etc.) have been much less problematic. Most of the work described in this chapter is only in the development or early application stage. Therefore, on the basis of only very limited data on dehullers and some complete milling systems, it is very difficult to make many solid recommendations. Detailed publications describing new mills and the application of new dehulling equipment to sorghum grain are required. Such reports should include throughput, power consumption, maintenance requirements, a detailed description of the machinery, cost, and data on the efficiency of dehulling in terms of fat, ash, and color reduction and other nutrient losses. Parameters affecting the throughput or efficiency of dehulling should be studied and results at a number of extraction levels should be reported.

Ideally, comparative studies of dehullers yield the most valuable information. It is essential that the same variety and lot of sorghum be used in such studies since the performance of dehullers is markedly dependent on the characteristics of the grain. For example, throughputs can vary by a factor of 2 or 3 between a soft and a hard sorghum variety. Comparative studies need to be conducted to optimize the abrasive surface in

Figure 11. Photograph of the modified Udy cyclone mill used as a laboratory abrasive decorticating mill. (Shepherd 1979.)

dehullers to permit the most selective removal of hull layers and to maximize the yield of the edible product.

The quality criteria desired in the final flour must be accurately defined so that millers can modify or operate equipment with these objectives in mind. For example, low lipid content is a desirable flour attribute since it decreases the problem of rancidity. However, the germ must be removed to reduce the fat content and this has an adverse effect on the nutritional quality of the flour. Obviously, storage and nutritional studies need to be undertaken to determine the optimum level of germ removal.

Plant breeders should consider adopting small-scale milling equipment to insure the development of varieties with desirable traditional and mechanical processing characteristics. Ultimately, it may be possible to even select varieties which require little or no denuding to produce acceptable flour.

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Industrial Milling of Sorghum for the 1980s

L. Munck*, K. E. Bach Knudsen*, and J. D. Axtell**

If sorghum growing semi-arid countries are to be self-sufficient in cereals for food during the 1980s, industrial milling and marketing of sorghum food products have to be introduced as quickly as possible. However, endeavors to supply rapidly growing cities with locally grown sorghum come up against several severe obstacles.

First, in these countries sorghum is a crop for the subsistence farmer. There is very little sorghum on the market, in part because of distorted governmental food price policies. In many countries, imported cereals are subsidized and sold at a lower price than sorghum. In Tanzania, for example, a white maize product is currently sold at one third of that of grey whole milled sorghum flour, even though maize gives a good yield in only 2 out of 5 years.

Second, the milling process devised for sorghum has been based on traditional wheat and maize technologies. Therefore, highly acceptable white maize and wheat products rapidly gained a foothold on the urban markets, leaving sorghum as a low prestige food crop associated with the backwardness of rural areas. Thus even in countries where sorghum as a food has age-old traditions, it is nowadays regarded as a feed crop. However, in the rural areas, locally developed techniques such as hand pounding for decortication are still in use and produce highly acceptable products. In these areas soghum is preferred to maize. Unfortunately these local techniques are now rapidly disappearing, and it is therefore important to have them documented before it is too late.

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Determination of Needs Through Studies of Local Practices

Studying local practices is a prerequisite for a precise evaluation of the acceptability and nutrition of sorghum, and its role in a mixed food diet. Such knowledge will contribute to an adequate background for the future development of industrial processes. Plate 1 : c displays selected flour samples which are representative of the current situation in Tanzania (Eggum et al. 1982) regarding sorghum milling. It is seen that the hand-pounded, high-yielding variety 2Kx17/B/1 (comparable with Lulu D) is by far the most acceptable sample in terms of whiteness. The machine milled Lulu D sample, processed in a local village mill devised for rice, comes next in quality, while the commercial Lulu D flour is almost as dark as whole milled sorghum. In Tanzania the latter product is three times as expensive as maize flour. It goes without saying that the quantities of sorghum flour sold under these circumstances are extremely small. However, the yield-improved, short sorghum varieties of the Lulu D type (Lulu, 2Kx17/B/1. 2Kx89 in Figure 1) are not ideal for hand pounding (Eggum et al. 1982). It is seen from the cross sections of seeds in Figure 1 that they are much softer than the local Tanzanian hard varieties (T300, T236, T261, T295, and T275), which are preferred for hand pounding in the rural areas. If a fine flour of comparable whiteness is desired, the modern white varieties yield only about 50%, while yields from local types range from 73 to 83%. Furthermore it is seen in Table 1 that, using hand decortication, yields of nutrients (starch 61 % and protein 44%) are very low in the modern varieties exemplified by Lulu D. Comparable figures for the local varieties are 92% starch and 75% protein. It is therefore clear that presently introduced sorghums are unsuited for hand pounding. When decorticated to a yield of 80%,

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru, A.P.. India. Patancheru, A.P. India: ICRISAT.

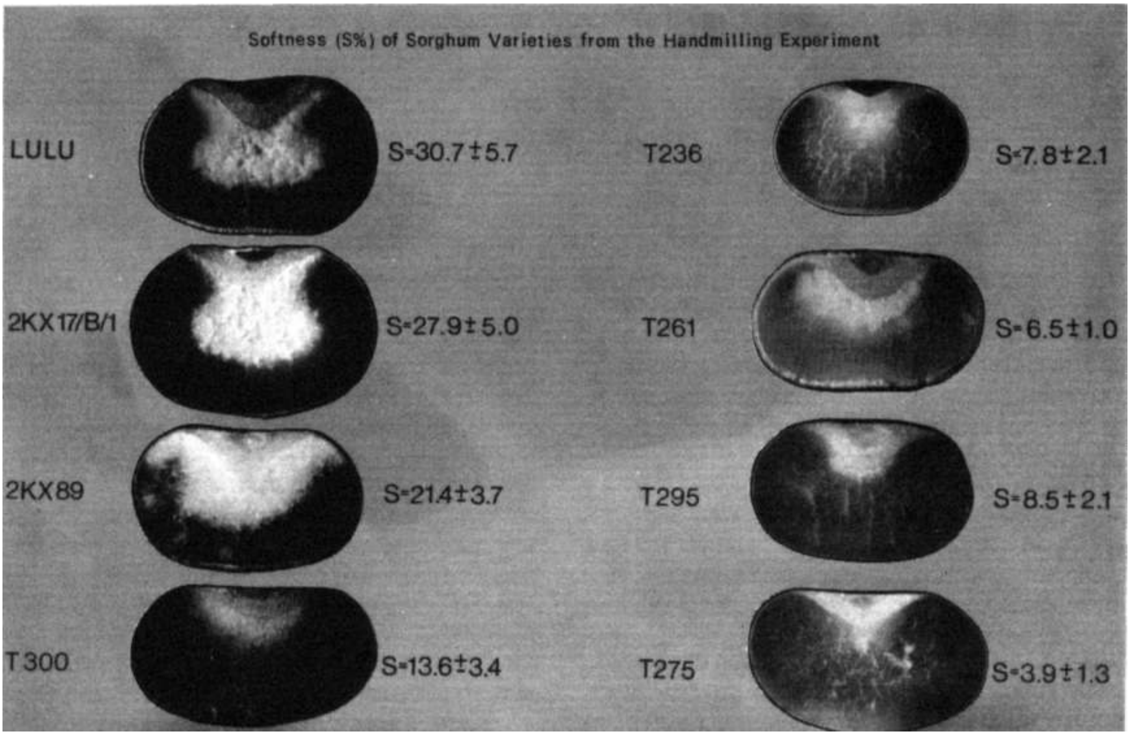

Figure 1. Photographs from cross sections of three yield-improved varieties—Lulu D, 2Kxl7/B/1, 2Kx89—and five local sorghum selections from Tanzania—T300, T236, T261, T295, and T275 (Munck et al. 1982). Normal incident light in a microscope with antiflex cap on the Ax objective.

Table 1. Milling yield, starch, protein content (% d.m.) and Agtron reflectance of raw materials and products and final yield of nutrients from locally decorticated sorghum varieties in Tanzania and milled in the United Milling Systems (UMS) sorghum milling process (Munck et al. 1982).

	Number of decorti-cated	Milling yield %	Starch % dm	Protein % d, m.	Yield of Starch %	Yield of Protein %	Blue Agtron reflectance
5 local varieties							
Raw material			724	11.7			29-39
Hand decorticated	3	78	855	11.2	92	75	50-55
Lulu D							
Raw material			69.7-71.8	138-12.5			26-32
Hand decorticated	4	50*	85 4	122	61	44	44
Village machine mill decorticated	2	50*	80	12.3	58	45	40
UMS sorghum milling system	1	80	83.0	12.0	93	77	51

* Approximate figures calculated on the basis of starch in hull flour.

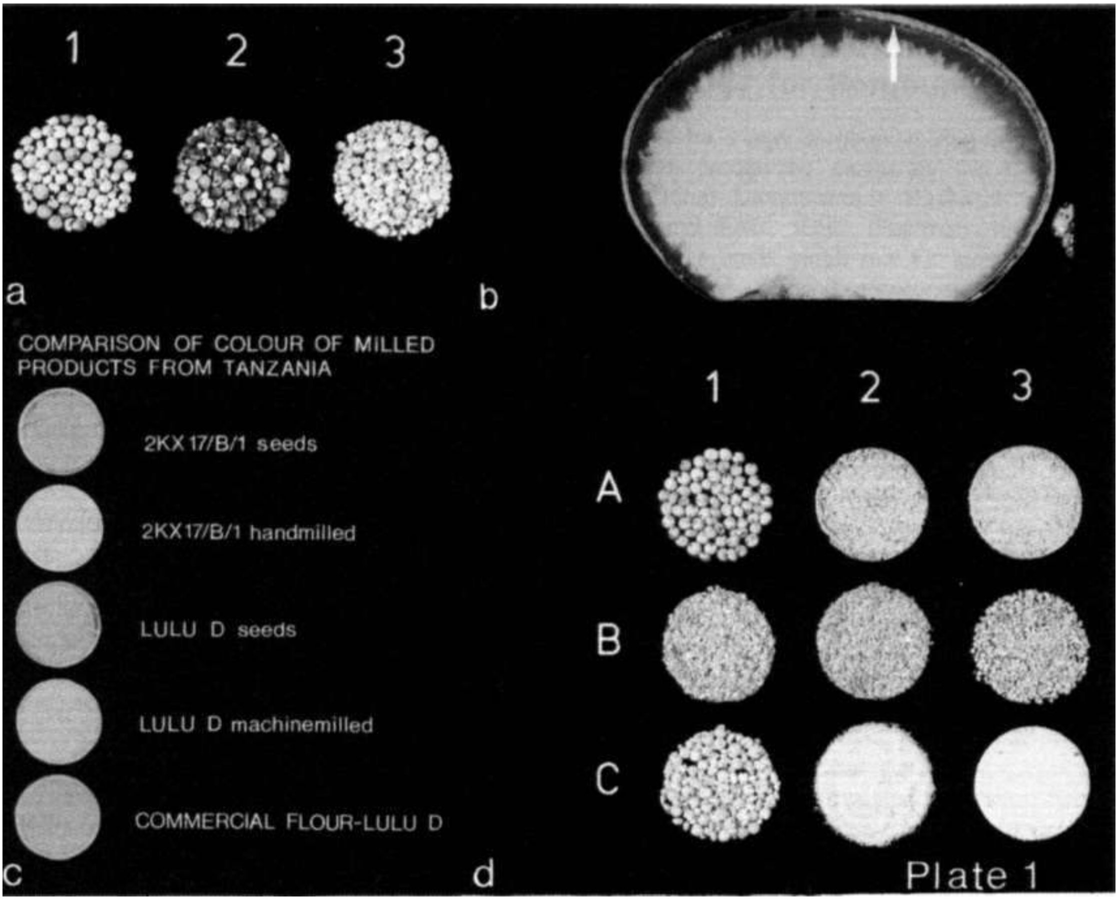

Plate 1 :a. The sorghum mixture (1) of African origin, which contains mainly a white sorghum cultivar, is slightly decorticated in the UMS DVA decorticator (2). The black testa layer under the white pericarp is now visible. In (3) the same sample is optimally decorticated in the sorghum milling system (Fig. 4) also using the UMS DVA decorticator, efficiently removing the brown testa layer.

1 :b. Micrograph of a cross section of a white sorghum seed from Plate 1 :a (1). The picture is taken in a fluorescence microscope with FITC filters. Pigments are seen migrating from the testa layer marked with an arrow. The pericarp + testa + the contaminated endosperm part have to be removed in the decortication process (Plate 1 : a [3]) .

1 :c. Comparison of color of milled products from Tanzania.

1 :d. Dabar sorghum and its products milled in the UMS sorghum milling process, displayed in Fig. 3.

which is a reasonable figure with the current food situation in Tanzania, the products will be much darker than products made from the local hard varieties, and thereby paving the way for competitive maize products.

Hand pounding is hard and tedious work. It takes up to 1 hr to process 2 kg of sorghum. Thus there is a ready market for small diesel-driven village mills serving individual farmers who bring their own batches to the mill. However, in our experiment (Table 1) we showed that such a technique is just as dependent on endosperm hardness as the hand pounding technique. Milling of Lulu D in a Tanzanian village mill gave a darker flour (Plate 1 : c) than a hand decorticated flour from the comparable variety 2Kx17/B/1 and just as intolerably high losses of starch and protein as the latter (Table 1).

Nutritional Quality of Sorghum Products

The content of digestible nutrients in low-tannin sorghum products is very high compared with other cereals (Table 2, Eggum et al. 1982). The true digestibility of protein and energy in decorticated grain is 100% and 96% respectively. When sorghum is cooked to make *"ugali"* porridge, these values decrease by 8% and 2% respectively. Although the digestibility of sorghum decreased through cooking, the values before and after cooking, are comparable with the best values for other cereals such as wheat, maize, and rice. However, the lysine value is very low (Table 2) and decreases by 40% during decortication. Because lysine is the nutritionally limiting amino acid in sorghum, the biological value of sorghum protein is the lowest of all cereals. By supplementing with lysine-rich foods such as beans and vegetables, the high potential of digestible protein and energy in sorghum can be fully utilized.

Developing a New Milling Technology for Sorghum

The need for a new sorghum milling technology has been recognized earlier by the Canadian International Development Research Centre (IDRC) and FAO. IDRC (Eastman 1980) has developed a small batch mill for local machine milling of sorghum using carborundum or silicium stones. Likewise, FAO has initiated a program for sorghum milling (Perten et al. 1978) on an industrial scale. This system also relies on an abrasive principle.

Mechanisms of hand pounding are very different from those of abrasive milling. In hand pounding the pestle causes a mechanical shock which generates strong interactive forces in between grains as well as between grains and equipment. When water is added, large flakes of hull material are formed. On the other hand, in abrasive milling the polishing effect is mainly obtained between the grinding stones and the seeds and as action of seeds against seeds, thereby producing fine bran particles. Abrasive milling through kernel breakage causes losses of endosperm in the bran fraction. However, hand pounding initially produces coarse endosperm particles that dwindle during the successive cycles of decortication. At the Carlsberg Research Laboratory we have developed an industrial decortication process aimed at avoiding the disadvantages of abrasive milling and incorporating the advantages of the age-old hand pounding principle (Munck et al. 1982).

In the new decortication machine (Fig. 2) (UMS DVA, United Milling Systems A/S, DK-2500 Copenhagen-Valby, Denmark) the sorghum ker-

Table 2. Nutritional quality in rat tests of the improved variety 2Kx17/B/1 (comparable with Lulu D) and the hand decorticated grain at well as the cooked product *ugali* (Eggum et al. 1982).

	True digestibility protein	Digestible energy	Biological value of protein	Lysine g/16gN
Whole grain	95	90	56	2.0
Hand decorticated grain	100	96	47	1.2
Ugali	92	94	49	1.2

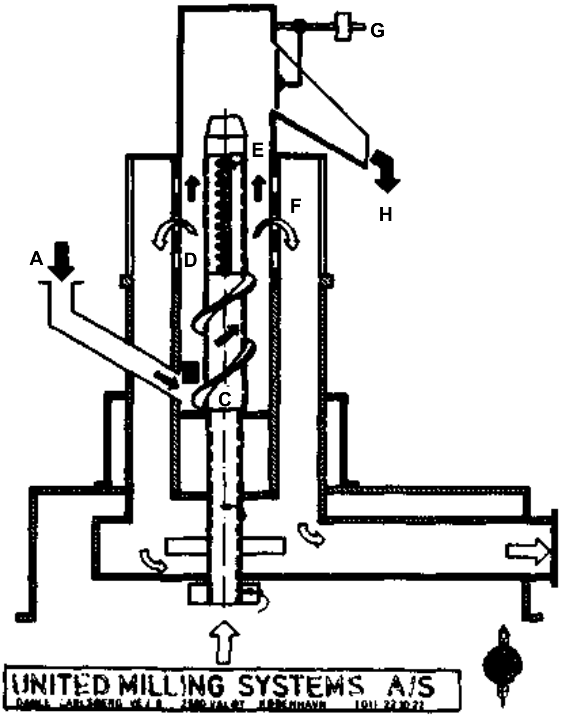

Figure 2. The United Milling Systems DVA sorghum dehuller (Munck et al. 1982).

nets are conveyed by a screw (C) into the decortication chamber (D), where a steel rotor rotates the grain mass towards the cylindrical screen (F). The pressure between the seeds during decortication can be controlled by the counterweight (G) in the outlet (H). The hulls and the endosperm fragments from the cracked kernels are discharged through the screen by an air current at high pressure. This fraction—the screen flour—is sucked out from the bottom of the machinery into a cyclone.

The first crucial point in the new dehulling process is described in Figure 3, where the UMS DVA decorticator is integrated into a milling system with a capacity of 2 t/hr. This is done in order to recover endosperm particles from the screen flour. After separating the fine bran fractions from the coarse ones through sifting (A2), the coarse fractions are separated by aspiration into an air sifter (B1) producing coarse bran (B2) and cleaned endosperm fragments (B3). The latter could then be milled together with the decorticated kernels (C1) in a milling and sifting section. Thus grits and flours of a high yield are produced. Products from the various stages in this process are displayed in Plate 1:d.

The new UMS DVA dehuller can, depending on the processing conditions, remove whole embryos, which produce sharp-edged decorticated, degermed kernels resembling children's milk teeth. This indicates that the UMS DVA dehuller produces a small amount of fine endosperm flour compared with abrasion mills, which tend to produce round seeds. Seeds decorticated with abrasive stone mills are more rugged on the surface and thus appear whiter than seeds from the UMS DVA decortication, which still have intact natural endosperm surfaces. Obviously the rugged surface indicates losses of fine particles of endosperm. Breakage of kernels does not affect yield in the new milling process as much as when the abrasive polishing technique is used. The reason is that, in the new process, losses can always be regained from the screen flour, as long as the endosperm particles are kept sufficiently coarse. For example, grains of Lulu D milled in the new process (Table 1) yield 78% of decorticated grains and 2% of endosperm fragments, rendering a total yield of 80% with lighter color than flour of the same variety milled locally in Tanzania yielding about 50%.

It is also seen that the yield in the product from Lulu D of the most important nutrients, starch and protein, in the new process is 93% and 77%, respectively. These figures are comparable with the yield from the hand pounded local hard Tanzanian sorghum varieties and much higher than the yield of these nutrients in the hand decortication of the high yielding Lulu which has a soft endosperm.

From a nutritional point of view, pericarp and testa should be removed in the decortication process, as they contain very small amounts of available nutrients (Eggum et al. 1982). They are also the main contributors to color in the final product. With the new milling process it is possible to retain most of the nutritious germ if desired, or remove it completely while processing sorghum for brewers' grits.

Utilizing high-tannin sorghums with a thick testa layer is very difficult. Tannins are nutritionally detrimental as they drastically lower the digestibility of starch and proteins. They are also potent carcinogens. In countries in Africa, high-tannin sorghum types are mainly used for beer. Plate 1 : a (1) displays a mixed sorghum sample consisting mainly of chalky, white sorghum seeds from Africa. Under the white pericarp these seeds have a dark testa layer (Plate 1 :b). Due to weathering,

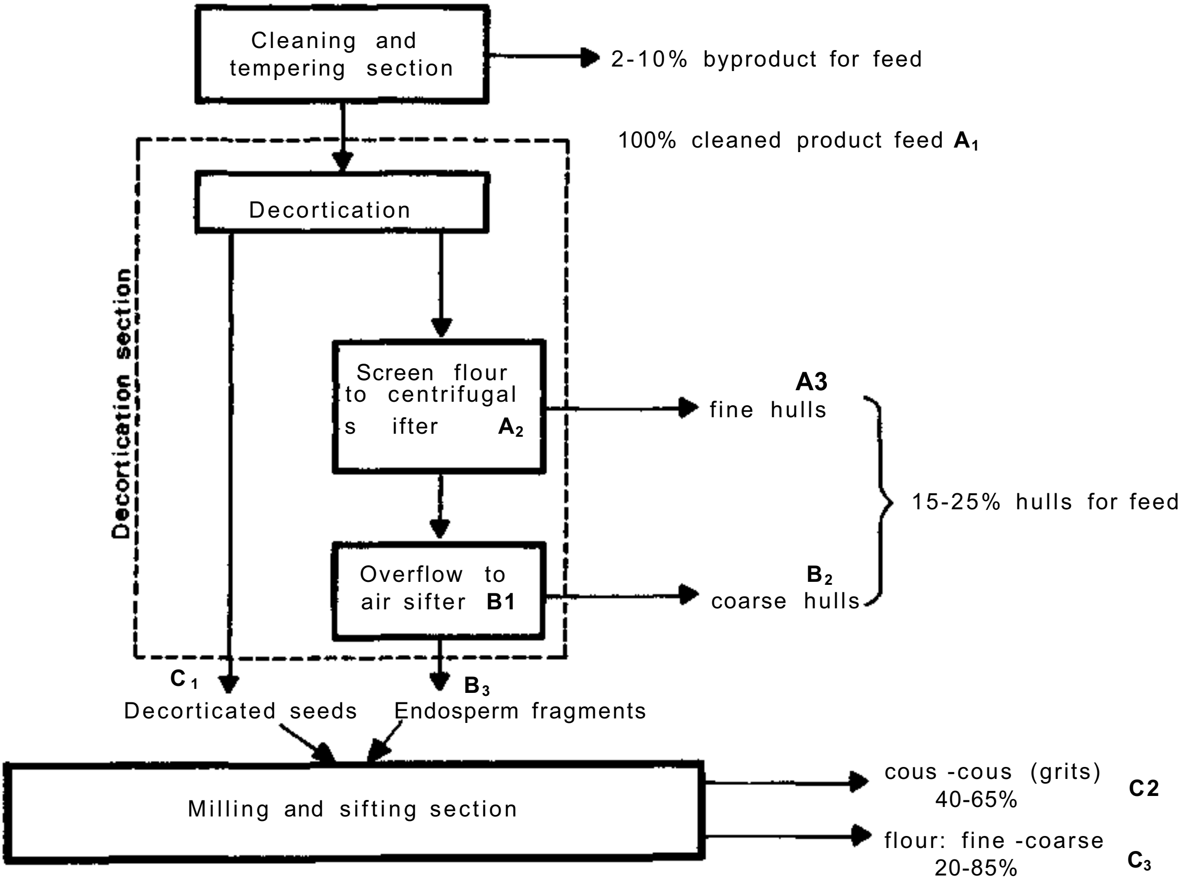

Figure 3. Flow scheme for the new industrial sorghum process (2 t/hrj developed at the Carlsberg Research Center, Copenhagen, in cooperation with UMS (United Milling Systems, Gamle Carlsbergvej 8, DK-2500 Copenhagen, Denmark). The UMS DVA decorticator (Fig. 2) is used in this process. Products according to the denotations are displayed in Plate 1:d: (A1) raw material, (A2) screen flour from decorticator, (A3) fine hulls from centrifugal sifter, (B V coarse hulls from centrifugal sifter, (B2) light coarse hulls from air sifter. (B3) heavy endosperm fragments from air sifter, (C1) decorticated seeds, (C2) grits, (C3) flour.

pigments from the testa layer have diffused into the endosperm. It is amazing to see how the product turns darker when such seeds are slightly decorticated in the decorticator [Plate 1 : a (2)]. By proper tempering and milling (Fig. 3) a white product is obtained at a yield of about 70%. These results point to new possibilities for utilizing bird-resistant high-tannin sorghum types for milling. An important task for plant breeders is to improve weathering characteristics of such varieties. If it is possible to develop high-tannin sorghum varieties with stationary tannins that cannot diffuse into the endosperm, such varieties could be well suited for the milling technology described above.

However, an adequate control of tannin content in milled products from high tannin sorghums as well as good cooking quality have to be secured. These prospects call for a closer cooperation between plant breeders and milling technologists. In fact, plant breeding should be combined with the development of new mills so that varieties and processes could be bred together.

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Evaluation of Sorghum Food Quality

L. W. Rooney and D. S. Murty*

Sorghum (*S. bicolor* L. Moench) is a staple commodity in several parts of the world and ranks fifth as a cereal crop in terms of production and utilization. However, the food quality of sorghum has not yet been clearly defined, probably because it is not used in commercial foods to the extent that wheat, rice, and maize are utilized. In sorghum consuming areas, only limited quantities of the product appears in metropolitan markets, and there are few if any standards available to distinguish grain quality, which is evaluated primarily by subjective criteria such as kernel color, appearance, size, and shape.

Crop improvement programs have become increasingly conscious of these factors that affect sorghum production and utilization (Murty and House 1980), and are attempting to exploit the vast genetic resources available to improve sorghum quality. The objectives of quality breeding programs in the past were frequently vague because selection criteria for quality were ill defined or poorly established. Recently, however, considerable progress has been made to devise standard laboratory methods to evaluate the quality of the finished sorghum products. This paper discusses the major sorghum food products consumed, reviews information on the extent of genetic variation for the preferred food quality traits, and describes potential methods that could be applied in sorghum breeding programs. Only a brief discussion of sorghum structure, milling, and food properties as related to future food uses of sorghum will be made as it relates to sorghum breeding programs. More detailed presentations on these aspects were made in the International Symposium on Sorghum Grain Quality.

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Structure of the Sorghum Grain

Structure of the grain has an important bearing on various processing and food quality traits. The structure of sorghum kernels varies significantly because of environmental and genetic factors. The shape, size, proportion, and nature of the endosperm, germ, and pericarp, the presence and absence of subcoat, and the color of the pericarp are all genetically determined. Rooney and Miller (1982) gave a complete description of the detailed structure of sorghum grain. The caryopsis, or kernel is composed of three main parts, the outer covering (pericarp), the storage tissue (endosperm), and the embryo (germ). An understanding of kernel structure and kernel properties is essential in order to comprehend sorghum quality characteristics. We will review briefly the essential parts of structure.

Pericarp

The pericarp can be subdivided into the epicarp, mesocarp and the endocarp. The epicarp is outermost and usually consists of two to three cell layers. These cells are long and rectangular in shape and contain wax and, occasionally, pigments. The mesocarp which underlies the epicarp may vary in thickness. When the mesocarp is thick and contains small starch granules, the kernel has a chalky appearance. Pearly sorghums have a very thin mesocarp that does not contain starch granules. The innermost layer of the pericarp is the endocarp, which consists of cross and tube cells. The cross cells are long and narrow with the long axis at right angles to the long axis of the kernel. One of the main functions of cross and tube cells is the transportation of moisture. These cells are also the breakage points when the pericarp (bran in milling terminology) is removed during milling of the grain. The pericarp varies in

International Crops Research Institute for the Semi-Arid Tropics. 1982 Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81. Patancheru. A.P., India Patancheru. A.P. India: ICRISAT.

thickness within a kernel and between kernels within a sample of sorghum. Genetically, the presence of starch in the mesocarp is controlled by the Z gene (Rooney and Miller 1982). Actual thickness of the starchy mesocarp may be controlled by modifiers since thickness of the starchy mesocarp does vary among cultivars.

Testa

Just beneath the pericarp, some sorghum kernels have a highly pigmented layer called the testa or subcoat. Some sorghum lines contain a partial testa that is found at certain places around the kernel. The testa also varies in thickness from one line to another and from one area of the kernel to another. The color of the testa varies among sorghum lines. Pigmentation is associated with a high concentration of polyphenols which apparently differs considerably among sorghum lines with a subcoat (Bullard et al. 1980). Presence of a pigmented testa is conditioned by the complementary genes B_1 and B_2 (Rooney and Miller 1982).

Endosperm

The endosperm of sorghum consists of the aleurone layer, and the peripheral, corneous, and floury portions (Fig. 1). The aleurone cell layer located beneath the pericarp (or testa, if present) is a single layer of block-like rectangular cells. The aleurone cells have spherical bodies that vary in size which contain protein, phytin, minerals, water soluble vitamins, autolytic enzymes, and high levels of oil. They do not contain any starch granules.

The peripheral endosperm is beneath the aleurone layer and is an illdefined area consisting of the first 2-6 endosperm cells. These cells are small and blocky and contain small starch granules embedded in a dense proteinaceous matrix. The matrix protein is comprised mainly of glutelins (alkali soluble proteins) and prolamins (alcohol soluble proteins).

The corneous endosperm (hard, flinty, horny, vitreous) located beneath the peripheral endosperm has a continuous interface between the starch and protein. The starch granules are very angular or polyhedral in shape with depressions where protein bodies were trapped between expanding starch granules.

The floury endosperm areas have loosely packed endosperm cells. The starch granules are spherical and they are not held together by the protein matrix. In addition, small voids occur between starch granules and there is relatively little continuous protein matrix. The air spaces alternating with cell constituents diffuse light as it passes through the endosperm which explains the chalky or opaque appearance of the floury endosperm.

The relative proportions of the corneous to floury endosperm is termed kernel texture or endosperm texture. Kernels vary from corneous to floury depending upon genotype and environmental conditions. Endosperm texture plays a major role in determining sorghum quality.

Grain Processing Properties: Variation Among Genotypes of Sorghum

The milling properties of the grain, and consequently flour quality are affected by the structure and moisture content of the grain as well as the milling equipment, and grinding technique. Traditionally sorghum was often dehulled before grinding into flour and grits. Grain was moistened in the mortar and pounded by hand with a pestle. High endosperm recovery with minimum breakage of the endosperm and complete removal of the pericarp are desired by consumers. Striking differences between genotypes for denuding quality evaluated by traditional methods have been reported (Murty and House 1980: Scheuring et al. 1982). Those grains possessing a thick pericarp and highly corneous endosperm produced the maximum quantity of decorticated grain without breakage, and with minimum effort and time required for pounding. Floury endosperm types and corneous endosperm types with a thin pericarp were relatively less desirable for hand processing. Conversely, grains combining a thin pericarp and corneous endosperm have proved acceptable for machine denuding (Maxson et al. 1971; Shepherd 1982; Reichert et al. 1982) and endosperm recovery was positively correlated to grain with a more corneous endosperm. Shepherd (1979) and Oomah et al. (1981) developed two different prototype laboratory decorticating mills which require only 5 to 30 g of grain for denuding. These prototype laboratory dehullers could be useful to evaluate the milling characteristics and food products made from dehulled grains.

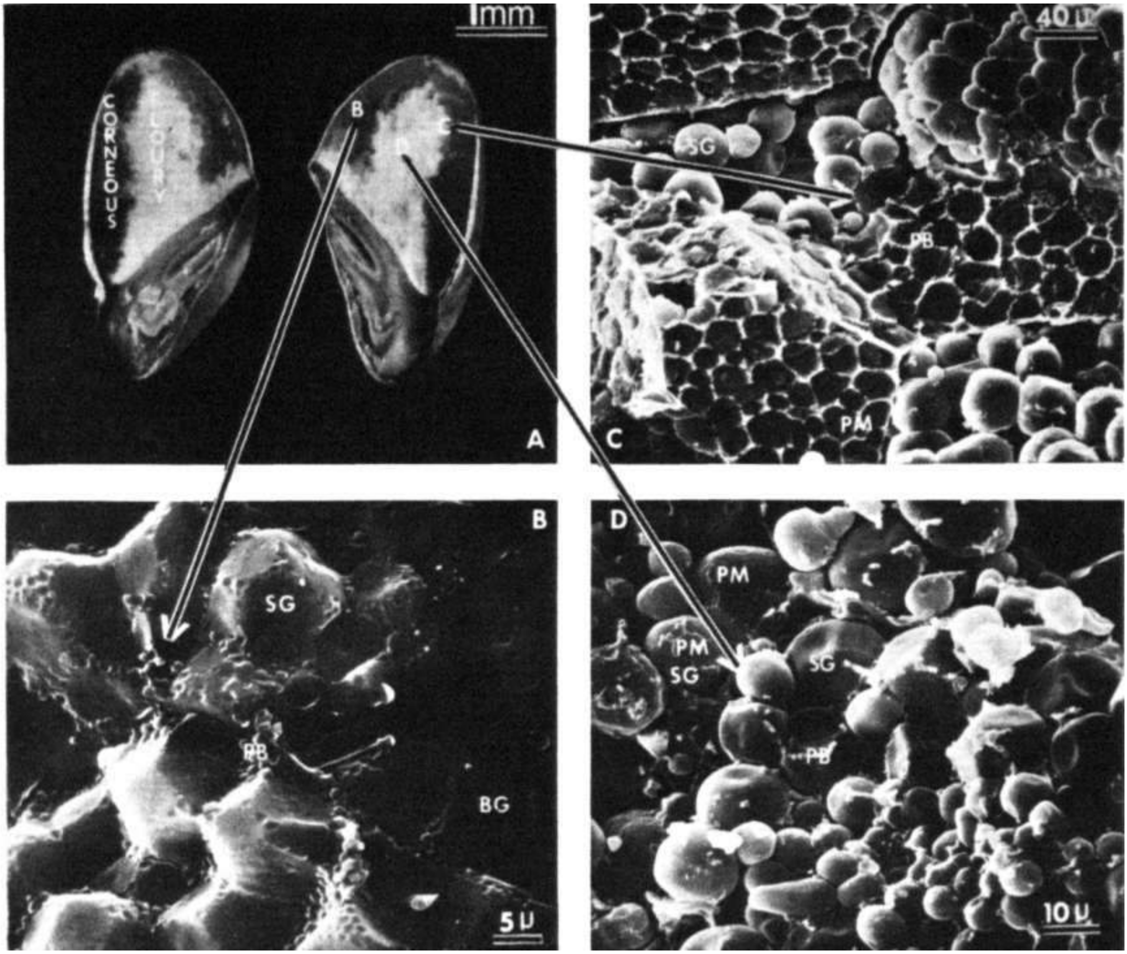

Figure 1. Scanning electron photomicrographs illustrating starchy endosperm structure: (A) longitudinal half kernel, (B) corneous endosperm area. (C) transition zone between corneous and floury endosperms, (D) floury endosperm area. SG-starch granule, PM -protein matrix, PB-protein body, BG-broken granules.

Shepherd's technique has been used by Da et al. (1982) to determine the milling properties and *to* quality of grain from individual F_2 heads. The milling technique clearly showed that sorghums with thick and thin pericarps differed in ease of milling.

Sorghum Food

Considerable progress to define grain quality has been made since the early 1970s. A great deal of interest has been shown and real progress made during the past 5 years and the ground work for continued progress is in place.

Vogel and Graham (1979) have given a detailed description of the various methods of sorghum consumption in the world. Questionnaires, correspondence, and field evaluation visits in Africa, Asia, and Latin America with various scientists have revealed that most sorghum produced for food is consumed in the following eight basic methods:

1. Unleavened bread —*roti, tortilla*
2. Leavened bread —*injera, kisra, dosai*

3. Thick porridge —to, *tuwo. ugali. bogobe, sankati*
4. Thin porridge —*ogi. ugi. ambali, edi*
5. Steam cooked products —*couscous, wowoto,* noodles
6. Boiled sorghum —*soru*
7. Snack foods —popped sorghum
8. Alcoholic and non-alcoholic beverages —*burkutu, busa, ting, obushera. abrey*

The products are referred to by many different names. Considerable variation exists in the exact techniques used to prepare products within each basic category. Usually, the differences observed in the actual preparation from one area to another and among households do not affect the quality of the grain. However, thick porridges are an exception.

Porridges are processed using acid, neutral, and alkali conditions (Rooney and Kirleis 1979). A sorghum variety with good porridge-making properties under acid or neutral conditions may not have acceptable quality when processed with alkali (Scheuring et al. 1982; Da et al. 1982). Thus, a variety like E35-1 that makes excellent acid *to* in Upper Volta has poor alkali *td* quality in Mali.

Variation for the Preferred Food Quality Parameters

Several workers have evaluated the grain processing and food quality traits of sorghum cultivars, particularly those of recent origin, in comparison with traditionally grown cultivars (Rao et al. 1964; Viraktamath et al. 1972; Pattanayak 1977, 1978; Scheuring et al. 1982; Obilana 1982; Juarez 1979; Khan et al. 1980). Large differences were reported among genotypes for various food quality traits.

Recently, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) carried out International Sorghum Food Quality Trials (ISFQT) in collaboration with various scientists in Africa and the Americas using grain samples from 25 cultivars grown in each of two years. It was found that the genotypes exhibited significant variation for quality traits over a range of food products (Murty and House 1980). Important findings of various sorghum food quality studies carried out in the past by various-workers are summarized below for the major food products consumed in the world.

Unleavened Bread

Roti

In India, sorghum is ground into flour which is made into unleavened bread called *roti* or *chapati.* Maldandi-35 sorghum grown in the postrainy season is the most preferred cultivar for *roti* quality. The kernels of Maldandi are large, with a thin white pericarp and an intermediate endosperm texture. The characteristic size, shape, and luster of Maldandi grain sets the standard for sorghum quality in India. Maldandi types of sorghum cost the most in the grain markets. Grain from the new improved hybrids has, in general, a relatively poor *roti* quality and demands a lower price.

Consumer cooking trials, laboratory taste panels, and standardized *roti* making procedures have consistently shown that sorghum cultivars produce *rotis* with vastly different acceptabilities (Rao et al. 1964; Rao 1965; Anantharaman 1968; Viraktamath et al. 1972; Waniska 1976; Murty and House 1980; Murty et al. 1982a).

Murty and Subramanian (1982) used a standardized procedure to produce *roti* from different sorghum cultivars. Taste panel tests using sorghum consumers as panelists clearly documented that variation among sorghums that had acceptable evident quality existed. Murty et al (1982a) observed that the kneading and rolling quality of the dough and the taste, aroma, texture, and keeping quality of the *roti* varied among the several hundred cultivars studied. Typical variation among some pearly white cultivars is presented in Table 1. In general, *roti* made from grains with a pale yellow-white color, with an intermediate endosperm texture, without a subcoat and with a thin pericarp had acceptable organoleptic quality. Presence of a tough, leathery pericarp produced *rotis* with inferior texture and flavor. Floury grains produced a poor quality dough while waxy grains produced a sticky dough and gummy *rotis.*

The physical and chemical properties of sorghum that significantly affect *roti* quality are only partially understood (Murty et al. 1982a; Subramanian and Jambunathan 1982).

Tortilla

Tortilla, a form of unleavened bread usually prepared from alkali cooked maize, is consumed in Mexico and Central America. However, in some

Table 1. ***Roti*** **quality characters of sorghum cultivars with pearly white grains with 40-60% corneous endosperm.**

Genotype	Rolling[a] quality	Roti[b] Color[c]	Taste	Texture	Aroma	Keeping quality
M-35-1 (Check, PS. Mohol)	223	144	1.3	1.4	1.1	2.0
CSH-8	23.0	118	2.0	2.0	1.8	2.2
Local Market (Maldandi)	23.2	144	1.3	1.3	1.0	1.8
SPV-101	23.2	144	2.1	2.4	1.5	2.0
SC-423	22.9	144	2.6	2.7	1.7	3.5
SC-110-1.14	22.8	118	2.9	3.3	2.1	3.0
8272-1	22.9	144	2.3	2.7	1.8	2.3
M.36116	22.2	143	1.3	1.4	1.0	2.3
M.36270	21.6	143	2.0	22	1.0	3.0
52-1	22.5	144	1.3	1.6	1.0	1.5
285 (R. Nagar)	22.3	144	1.3	1.6	1.0	1.5
SEM	±0.1	±0.1	0.04	0.04	0.03	0.04

a. Evaluated by measuring the diameter of the *roti* obtained by continuous rolling of dough from 30g flour with a pin until the *roti* breaks.

b. Based on the scores of a trained taste panel of five members on *rotis* made from grain samples of the postrainy season harvests grown at ICRISAT Center, 1978. Taste, texture, and keeping quality were scored on a scale of 1 to 5 (1 = good) while aroma was scored on a scale of 1 to 3 (1 = good),

c. All color codes refer to white or pale yellow grades of Munsell's Soil Color Charts (1975).

countries sorghum or blends of sorghum with maize are made into *tortillas.* Bazua et al. (1978) and Khan et al. (1980) found that color was a major factor limiting the acceptance of sorghum *tortillas.* Khan et al. (1980) described laboratory methods for *tortilla* evaluation and noted that color of sorghum *tortillas* made from 38 cultivars varied from a light yellow to dark greenish brown. The cooking time and the wet milling properties of the *nixtamal* were affected by grain size, texture and structure. Sorghum grains without a subcoat, with intermediate texture, colorless pericarp, and low polyphenol content produced the best *tortillas.* Sorghum kernels with visually similar characteristics have significantly different *tortilla* making potential (Iruegas et al. 1982; Khan et al. 1980).

Leavened Breads

Injera

Sorghum is consumed in Ethiopia in the form of a thin leavened bread called *injera.* The grain is milled into flour which is mixed with water and a starter culture and the mixture is then stored for 2 to 3 days. Cooked sorghum flour is added to the batter just prior to pouring it onto a hot griddle for cooking. The thin pancake is flexible, has a large number of evenly spaced "eyes" on the surface and remains flexible after overnight storage.

Poor texture is the major factor that limits the acceptability of many sorghum cultivars for *injera* (Gebrekidan and Gebre Hiwot 1982). Soft endosperm types with white or red pericarp, regardless of subcoat presence, produced the best *injera.* However, brown sorghums with high levels of tannin produced unacceptable *injera.* Among the soft sorghum varieties that appeared the same visually, significant differences in keeping properties of *injera* were observed (Table 2). A high yielding sorghum cultivar (Gato-994) from the Ethiopian Sorghum Program was not grown by farmers primarily because it produced poor quality *injera* (Gebrekidan and Gebre Hiwot 1982).

Kisra

Kisra is a leavened sorghum bread made from

Table 2. *Injera* quality parameters of selected sorghums from the International Sorghum Food Quality Trials in 1980.

		Injera			
Genotype	Grain	Softness	Color	Taste	General desirability and remarks
M-50009	Pearly white, hard	soft	white	very good	Trace of bitter taste
M-50013	"	dry	bright white	good	Tastes and looks like maize *injera*
M-35052	"	dry	white	poor	Has maize taste
M-50297	"	dry	yellowish	poor	Dries too fast
CS-3541	"	dry	white	poor	Overall poor
Market-1	White, hard	dry	white	bad	Bad aroma and taste but good eyes
CO-4	Red	very soft	reddish	very good	Very good
WS-1297 (check)	Chalky white subcoat present	very soft	brownish	excellent	Similar to *teff,* excellent
IS-7035	"	dry	reddish	very good	Eyes are as good as *teff*
IS-7055	Brown subcoat present	dry	reddish	bad	Very bad eyes
IS-2317	White subcoat present	dry	reddish	bad	Bad aroma and taste but good eyes

Source: Gebrekidan and Gebre Hiwot (1982).

whole sorghum flour that is popular in the Sudan. In South India, a similar product called *dosai* is prepared. Information on variability for *kisra* quality characters among sorghum cultivars is limited. The *kisra* quality parameters of the 25 sorghum cultivars from the International Sorghum Food Quality Trials was determined (Murty and House 1980). In general, *kisra* made from grains with cream color and less than 40% of the endosperm corneous had the best texture and keeping properties. Genotypes with high tannin and phenol content were rejected in the consumer tests.

Thick Porridges

The use of sorghum to prepare thick porridges which are consumed with various sauces, stews, and soups is of major importance in Africa and India. In general, the porridges can be classified into porridge with acid, neutral, and alkaline pH. The pH used to prepare the porridge significantly affects texture, taste, color, and keeping quality of the product (Scheuring et al. 1982; Da et al. 1982). Alkali pH affects the color and texture of the porridge most significantly. Thus, the porridges. for purposes of grain quality evaluation, must be divided into three groups. A fourth group would be fermented porridges which we will cover separately. Our current information suggests that acid, fermented, and neutral porridge quality are similar but alkaline porridges are different. For example, E35-1 makes good acid and neutral *td,* but alkali *to* of E35-1 has poor keeping properties.

Acid Porridge

Sorghum is consumed in Upper Volta in the form of a thick porridge called *td* and is prepared using tamarind water, i.e., an acidic pH. Pattanayak (1977, 1978) reported that the best quality *td* is produced by the West African local varieties with a white pericarp and highly corneous endosperm. *Td* made from introduced cultivars was frequently soft and sticky with poor keeping quality. In addition, the introduced cultivars had a softer endosperm texture, which greatly reduced yields of decorticated grain. The combination of poor milling properties with poor *td* texture severely limits potential production of the introduced varieties. We now have sufficient information and laboratory techniques to select varieties with

Table 3. Cultivar differences for acidic *td* quality among visually similar, white and corneous endosperm types.'

Genotype	Color	Taste	Texture	Keeping quality
M-50013	1.8	2.5	2.7	1.7
S-29 (Check)	1.8	1.9	1.7	1.8
SPV-8	1.4	2.0	1.6	1.3
IS-5758	1.2	2.0	1.8	3.1
IS-5452	22	1.7	1.9	3.0
CSH-6	1.5	1.7	2.0	24
SFV-352	1.7	3.0	2.9	2.6

a. Average of taste panel scores given by six Voltaic trainees on a scale of 1 to 5, where 1 is good (Murty and House 19801).

Table 4. Variation for *ugali* quality characteristics among cultivars with white pericarp and corneous endosperm.*a*

Genotype	Color appeal	Taste	Texture	Keeping quality
E35-1	15	1.8	1.5	2.0
IS-5341	1.5	1.8	1.6	2.4
UChV$_2$	24	2.4	2.2	1.8
IS-6928	15	2.0	1.6	1.9
E-6954	2.0	2.1	1.9	1.9
IS-2550	2.0	2.2	2.3	3.4

a. Average of independent scores of taste panel tests conducted in 1979 and 1980 on a sclae of 1 to 5 (1 = good) (Murty and House 1980).

good *td* quality in the breeding programs. *T6* properties varied considerably among grains that had similar visual characteristics (Table 3).

Neutral pH Porridge

The use of sorghum flour from dehulled or whole grain to produce a porridge without acid or alkali addition is quite common. Information on *td* made with water at nearly neutral pH is available (Obilana 1982; Boling and Eisener 1982; Murty and House 1980; Akingbala et al. 1981 a,b; Murty et al. 1982 b).

Taste panels were conducted on *ugali* samples from 108 sorghum cultivars (Murty and House 1980), which were prepared using a standard procedure. The results indicated that the color, keeping quality, and texture varied greatly with the sample population. A pale yellow or white *ugali* with little tackiness was preferred, although a light red *ugali* was acceptable provided that its taste, texture, and keeping properties were good. Highly corneous grains were found to yield the best ugali product. Grains with a waxy endosperm produced a thin product. Desired *ugali* qualities were associated with thick and viscous gel properties. Sorghums with similar visual properties differed in *ugali* properties (Table 4).

Sankati, a porridge made in South India was made from the ISFQT samples (Table 5). The desired quality characteristics were similar to *ugali.* Desikachar and Chandrasekhar (1982) found that sorghums with good quality for making porridges produced *rotis* with poor quality, which was similar to the observations in the ISFQT data.

In Tanzania and Nigeria, some new improved varieties have not been accepted for production because of either poor endosperm recovery or poor porridge making quality (Eggum et al. 1982; Obilana 1982). Some of the varieties, which matured early, were severely damaged by molds, and were too soft to mill. These observations

Table 5. ***Sankati*** **quality characteristics of sorghums with visually similar grain properties.**[a]

Genotype	Color	Taste	Texture	Keeping quality
M-35-1	1.9	1.8	2.5	2.5
CSH-5	1.3	1.3	1.7	1.9
M-50009	1.4	1.7	2.0	3.0
M-50013	1.5	1.8	1.5	1.7
M-35052	1.3	1.8	2.5	2.3
M-50297	1.6	1.7	1.8	1.8

a. Average scores given by five and six farm workers at two locations. Bhavanisagar and Anantapur (S. India), respectively (replicated twice) on a scale of 1 to 5 (1 = good). (Murty et al 1982b).

emphasize the importance of routine selection for food quality in breeding programs.

Alkaline Porridge

Alkali from ashes is used to cook sorghum flour into *td* in Mali and parts of Nigeria and Upper Volta. The quality of the local Malian sorghum cultivars for making *td* is excellent; but nearly all exotic sorghums produce poor quality *td* (Scheming et al. 1982). In addition, local Malian varieties produce *to* with good keeping characteristics over a broad pH range while some improved varieties are extremely sensitive to changes in pH. The observations in Mali have been confirmed by laboratory studies with Upper Voltaic sorghums (Da et al. 1982). Environmental factors significantly affect the quality of sorghums for use in alkali *td* (Scheuring et al. 1982).

Laboratory methods using grain from a single head of sorghum have been developed for thick porridges (Da et al. 1982). They will permit milling quality evaluation as well as evaluation of *td* texture. Scheuring et al. (1982) used a simple method based on cooking ground whole grain in alkali to produce *td* and evaluating *td* firmness subjectively after overnight storage.

Thin Porridges

Ugi is a thin porridge consumed in several countries of East Africa. Generally, a cream colored, smooth flowing product with a characteristic sorghum aroma is liked (Murty and House 1980). *Ugi* made from sorghums with a subcoat or brown pericarp tasted bitter. Another significant variation among cultivars for *ugi* quality was the gelling property of cooled *ugi.* Good *ugi* produced a highly consistent thick gel after cooling overnight. In general, sorghums with acceptable thick porridge quality will make acceptable thin porridges.

Fermented Porridges

Many porridges, thin and thick are made by fermenting either whole grain or flour from sorghums. *Ogi* production has been discussed by Obilana (1982) and Akingbala et al. (1981 a,b). The brown sorghums produced low yields of *ogi* with poor organoleptic properties. White or red sorghums produced the best *ogi,* with white preferred. Often, *ogi* is used as a thick porridge and stored where upon its quality parameters effectively resemble those of acidic porridges.

Boiled Sorghum Products

Pearled sorghum kernels are often cooked and used as a substitute or extender for rice. In Mali, coarse grits from a special kind of local sorghum called *kinde (margaritiferum)* is used for production of rice substitutes. *Annam* or *soru* (Table 6) properties of sorghum cultivars varied considerably among genotypes (Subramanian et al. 1982). In general, a sorghum that cooks, looks, and tastes like rice is preferred. Thus, kernels with a corneous endosperm and white pericarp are preferred. Cooking time ranged from 54 to 114 min while the volume after cooking increased from 100 to 273%. The increase in cooked grain volume was positively related to grain density. Keeping quality of the soru differed among sorghum samples with similar appearance (Table 6). Sorghums with light red pericarp produced acceptable products.

Table 6. Quality parameters of s*oru* from cultivars with visually similar characteristics.*

Genotype	Color	Taste	Texture	Keeping quality
M-35-1	1.7	1.2	1.1	1.6
M-50009	1.5	1.5	1.8	1.7
M-50013	1.3	1.5	2.0	2.1
M-50297	1.6	1.8	2.0	1.3
S-29	1.1	1.2	1.2	1.2
CS-3541	1.1	1.7	1.8	1.9
Market-1	1.5	2.0	2.0	1.8

a. *Soru* samples were evaluated by six farm workers at Bhavanisagar (S. India) on a scale of 1 to 3 (1 = good) (Subramanian et al. 1982).

Steam Cooked Products

Couscous is a granular product made by steam cooking agglomerated sorghum flour. It is popular in several West African countries. Sidibe et al. (1982) reported that a good *couscous* should neither be sticky nor dry. They found that the local *dagafara* sorghums with vitreous grains yielded more *couscous* product per unit of flour than other sorghums, and that the cohesion and integrity of the granules from *dagafara* flour were generally more desirable. All sorghums that produce acceptable *td* produce acceptable *couscous.* Therefore, selection for *td* quality may preclude the need to select for *couscous* quality. More information is required to determine if our current information is correct.

Snack Foods— Special Sorghums

In India, special sorghum cultivars have been puffed or popped (Ayyangar and Ayyar 1936; Desikachar 1980). Sorghum lines with excellent popping properties and other special uses were discussed by Prasada Rao and Murty (1982). Generally, the pop sorghums have a low germ to endosperm size ratio. The kernels are small with a medium thick white pericarp and corneous endosperm. Popping, although common in India, is seldom used to process sorghum in Africa. In India, the popped sorghum is often used to produce other snacks and in special foods prepared for children.

Sorghum Food Quality Classification

Data from the ISFQT has permitted an overall evaluation of whether it is possible to breed sorghums that have properties which would permit their use for almost all sorghum foods. The average acceptability scores of the various sorghum foods evaluated in the ICRISAT collaborative ISFQT are presented in Table 7. In general, varieties like CSH-5, M-50009, Mothi, and M35-1 which had pale yellow/white grains with 60-70% corneous endosperm produced products with acceptable quality for all the food systems. The effect of local conditions might change the acceptability drastically due to grain molds and other factors.

The specific food qualities of sorghum cultivars were related to kernel texture and pericarp thickness. Kernels with a thick pericarp and corneous endosperm texture had the best hand milling properties while the floury grains were in general rejected. The pearly grain types were not readily accepted by consumers using hand milling since they required more effort in decortication, but they can be mechanically milled to produce excellent products.

Grains with 60-100% corneous endosperm were preferred for the preparation of stiff porridges like *td, ugali, bogobe, sankati,* and for rice-like products. Grains with 20-40% corneous endosperm were suitable for preparation of *kisra* and *injera. Kisra* is mainly produced from ground whole grain fermented for about 24 hr. So the inability to decorticate floury sorghum is not important. A similar situation exists in Ethiopia

Table 7. Overall acceptability of traditional milling quality and a range of food products made from 25 sorghum cultivars.[a, b]

S. no.	Genotype	Endosperm[c] texture	Milling quality	*Roti* (1979 & 1980)	*Tortilla* (1979)	*Injera* (1980)	*Kisra* (1979)	*Ugali* (1979)	Alkali *td* (1979)	Acid *to* (1980)	*Bogobe* (1979)	Fermented *Bogobe* (1979)	*Sankati* (1980)	Soru (1980)
1	M35-1	3.0	3.0	1.0	1.5	1.5	2.2	1.5	1.0	2.2			2.0	1.4
2	CSH-5	2.0	1.5	1.0	1.2	2 0	2.3	2.0	1.0	1.9	1	1	1.0	1.4
3	M50009	2.0	1.7	1.5	1.5	1.5	3.4	2.5	5.0	1.7	—		1.5	1.6
4	M50013	2.0	2.5	1.5	1.5	3.0	2.7	2 5	1.0	2.2	—	—	1.0	1.7
5	M35052	2.0	2.5	2.5	1.5	4 0	2.8	1.5	1.0	1.4	1	1	2.2	1.6
6	M50297	2.0	2.0	1.5	3.0	4 0	2.2	2.3	1.0	2.5	—	—	1.0	1.7
7	P721	5.0	5.0	5.0	4.0	4.5	2.5	4.0	5.0	3.0	—	—	4.0	2.0
8	CO-4	3.0	2.0	3.0	4.0	1.0	2.0	2 7	1.0	2.7	1	1	2.5	1.5
9	P. Jonna	3.0	2.0	3.0	4.0	4.0	2 1	2 5	1.0	3 0	—	—	2.5	2.4
10	Mothi	2 0	1.3	1.5	2 0	4.0	2.5	1.2	4.0	2 2	—		2.0	1.5
11	E-35-1	1.0	2 5	1.5	2 0	3.0	2.1	1.5	2.0	1.1	1	1	2.0	1.6
12	IS158	(waxy)	3 0	4.0	3.0	5.0	4.3	5 0	5.0	4.0	—	—	5.0	2.4
13	WS1297	4 5	3.0	4.0	5.0	1.0	3 8	4 0	1.0	3.7	—	—	4 0	2.3
14	Swama	2.0	3.0	1.0	4.0	1.5	2.7	2 0	1.0	3.5	1	1	2.5	1.8
15	S-29	1.5	1.0	2.5	2.5	4 0	2 0	1.5	1.0	1.2	3	1	2.0	1.1
16	S-13	1.0	1.5	2.5	2.5	3.5	3.2	1.5	1.5	1.5	1	1	1.7	1.3
17	IS2317	3.0	4 0	3.5	4.0	4.5	2 6	3 5	1.0	2.2	—	—	3.0	1.5
18	IS7035	3.0	4 0	3.5	4.0	3.5	3 1	3.5	1.0	4.0	1	3	3 0	2.5
19	IS7055	3.5	4 0	4.0	4.0	4.5	3.4	3.5	1.0	4.2	1	3	3 5	2.0
20	IS9985	3.5	2 5	1.5	2.5	1.5	2.7	2 5	1.5	1.5	1	1	3.0	1.9
21	IS8743	3 0	2 0	3.5	4.0	1.5	3.3	3.0	1.7	4 0	—	—	3.0	2 0
22	Dobbs	4.0	5 0	5.0	5.0	5.0	4.4	5.0	3.0	3 2	3	3	5.0	3.0
23	CS3541	2.0	1.7	2.5	2.0	4.0	3 0	2.5	2.0	2.7	—	—	2.0	1.6
24	Segaolane	2.5	2.0	1.5	1.5	2.0	3.3	2.3	1.7	1.6	1	1	2.0	1.6
25	Market-1	1.0	1.2	2.0	3.0	4.5	—	1.5	1.5	1.0	—	—	2.0	1.8

a. Data from International Sorghum Food Quality Trials. The original data sources are as follows: *Roti*—D. S. Murty; *Tortilla*—L. W. Rooney, A. Iruegas, and G. Vartan; *Injera*—B. Gebrekidan; *Kisra*—H. Perten and S. Badi; *Ugali*—D. S. Murty; Alkali to—J. Scheuring; Acid to—S. Da and C. Pattanayak; *Bogobe*—N. Eisener; Sankati and *Soru*—D. S. Murty; Fermented *Bogobe*—N. Eisener. (Murty and House 1980)

b. Original data obtained on various quality parameters of each food product were averaged to give an overall score.

c. Endosperm texture was scored on a scale of 1 to 5 where 1 = completely corneous and 5 = completely floury.

where the sorghum flour is fermented for more than 48 hr to prepare *injera.* Grains with an intermediate texture were the most suited for producing unleavened breads *(tortilla* and *roti).* Therefore, sorghums can be grouped into classes depending upon texture of the grain similar to the USDA wheat classes. The soft sorghums would be most desired for leavened breads while the hard sorghums would be the most useful for porridges and rice-like products. The intermediate class could be most useful for unleavened breads.

In general, the brown sorghums with testa and spreader genes were unacceptable for all products evaluated. The presence of red or yellow pericarp did not adversely affect acceptance of most of the products as long as taste, texture, and keeping quality were acceptable. For example, in leavened breads, sorghums with a subcoat made acceptable products. The preferred color of porridges is white or yellow, but porridges from red sorghums are consumed. Even brown sorghums are consumed as porridges in some areas. Thus, color is not of critical importance in many of the rural food systems. However, color is critical for the unleavened breads, especially *tortillas.* On the other hand, if sorghum products are going to compete with maize and wheat foods in urban areas, a white color is needed for acceptance.

Effect of Environment on Food Quality

Genotype x environment interactions affect the chemical composition, physical properties and food quality of sorghum (Hulse et al. 1980; Shepherd 1982; Reichert et al. 1982; Rooney et al. 1980). It is clear that these interactions must be considered in sorghum quality testing programs as they are for other cereals (Heyne and Barmore 1965; Juliano 1979).

Environment significantly affects the quality of roti (Murty et al. 1982a), tortillas (Khan et al. 1980), and alkali and acid *td* (Scheuring et al. 1982; Da et al. 1982). The variations in quality are affected by drought, molds, weathering, insects, leaching of pigments and other factors. In general, the local varieties produced the most uniform quality *td* over different environments while introduced varieties varied greatly. The effect is on milling properties as well as organoleptic properties such as taste, color and texture, (Scheuring et al. 1982; Rooney et al. 1980).

Tests to Predict the Quality of Sorghum

It would be useful to identify simple physicochemical tests that could predict the quality of sorghum varieties for use in foods. Such tests have been used effectively for evaluating wheat and rice quality (Heyne and Barmore 1965; Juliano 1979). A major problem limiting the development of quick tests to predict sorghum quality was the lack of clearly identified cultivars with good and poor quality.

Amylose

The amylose content of sorghum does not vary as much as that of rice and has not been clearly shown to be related to food quality (Akingbala et al. 1982; Waniska 1976; Subramanian and Jambunathan 1982). The amylose content of 495 nonwaxy sorghum genotypes varied from 20 to 30% of the starch in the endosperm. Additional information to determine the potential value of amylose content is needed; but, amylose content of sorghum does not appear to be as important as it is for rice quality evaluation.

Alkali Tests

A test to predict the color of *tortilla* and alkali *to* by soaking five kernels of sorghum overnight or by boiling for 2 hr has been used by Khan et al (1980). The color of the cooked kernels or steeped kernels was evaluated subjectively by comparing with known standards. A variation of this method has been used by Iruegas et al. (1982) in Mexico. Waniska (1976) modified the alkali spread test that has been used successfully with rice by applying the alkali to milled kernels of sorghum. The method clearly distinguished waxy from nonwaxy kernels, but could not make clear distinctions among the ISFQT samples. A major problem may be the variability in milling damage to the decorticated sorghum kernels which causes variation in the rate of alkali absorption.

Gel Spread Tests

A number of tests based on gelatinization of flour water dispersions followed by measuring the consistency of the gel. appear promising but must be evaluated more carefully (Murtyet al. 1982c; Da et al. 1982). A significant association of swelling power and starch solubility with the cooking properties of boiled sorghum was reported (Subramanian et al. 1982). However, the correlations are low, and more information is required to evaluate the potential of these tests.

Amylograph Cooking Characteristics of Starch and Flour

The amylograph cooking characteristics of sorghum starches and flour have been tentatively related to food quality of sorghum (Waniska 1976; Akingbala 1980). The setback viscosity of the sorghum starch and flour was high for sorghums with acceptable thick porridge making quality and was low for sorghums with acceptable *roti* making properties. Similar observations were recorded by Desikachar and Chandrasekhar (1981).

Flour Particle Size

The particle size distribution and starch damage in a flour affect the quality of the flour significantly. Murty and House (1980) studied the flour particle size index (PSI) of several cultivars using the method of Waniska (1976) and found a range of 25-80 PSI among genotypes. PSI values were affected by grinding and sieving methods and were subject to considerable errors. However, the PSI was correlated consistently with the texture of the endosperm. Particle size measurements are important and should be given a high priority in future research in sorghum quality testing procedures.

Percent Water Absorption and Water Uptake

The amount of water absorbed by the grains after soaking them in water for 5 hr at room temperature has been expressed as percent water absorption (Murty and House 1980). This parameter showed a broad range of variation among various grain types and was negatively correlated with *roti* quality. Desikachar and Chandrasekhar (1982) found that water uptake of flour was related to dough and *roti* quality.

Texture Evaluation by Objective Tests

The single most critical property of sorghum foods that affects their acceptance is related to texture. Simple objective methods to measure texture are needed and are not readily available. Keeping quality is a critical factor that relates to texture measurements. The Instron universal testing machine has been used to measure texture of *to. tortillas,* and *roti,* and the hardness of individual sorghum kernels (Waniska 1976; Da et al. 1982; Johnson et al. 1979). However the Instron is an expensive sophisticated instrument that requires considerable expertise to operate. It is not practical in routine plant breeding programs. But, it is extremely useful to determine basic information on texture. Then the basic information can be used to develop "quick and dirty" tests that can provide screening techniques.

A few simple tests have been applied to sorghum *td* (Waniska 1976; Akingbala 1980; Da et al. 1982) such as the stickiness measured using double pan balance and softness using a penetrometer. Both techniques can be used to distinguish between *td* samples prepared from a single head of sorghum. The penetrometer provides a relatively low cost objective method which can improve upon the use of subjective methods.

Color Measurements

The Hunter Colorimeter, Agtron and other instruments can be used to measure color objectively in terms of reflectance, "a", and "b" values that measure the intensity of the primary colors. The instruments are expensive, require sophisticated maintenance, constant voltage, and are in general impractical in routine breeding programs. An effective inexpensive method is to compare the color of the product with that of standard color charts. Murty et al. (1979) have used the Munsell soil color charts to describe the colors of *roti.* A standard set of colors representing the range observed for the particular food product can be purchased inexpensively and easily. The correct Munsell plates can be selected by using an instrument to determine the range in color values for an array of the specific foods, or the soil color charts can be compared until the appropriate color match is obtained (Rooney and Murty 1982).

Endosperm Texture and Hardness of Grain

The proportion of floury versus corneous endosperm in the kernel is called endosperm texture. Endosperm texture is related to hardness, milling properties and cooking characteristics of the flour.

The most common method to evaluate endosperm texture is to cut 10 to 20 individual, sound representative kernels with a pocket knife. Then, the relative proportion of corneous to floury endosperm is rated subjectively on a scale of 1 to 5, where 1 = 81 to 100% corneous, 2 = 61 to 80%, 3 = 41 to 60%, 4 = 21 to 40%, and 5 = 0 to 20%. The texture of the endosperm is subject to environmental effects; variation among individual grains within a sample is common. In some samples, 20 or more kernels are sampled to secure an average value. Sophisticated laboratory facilities are not needed to do this and considerable progress can be made by using it in selection programs.

More accurate measurements of texture have been made by Munck et al. (1982) and Kirleis and Crosby (1982) who measured the relative proportion of corneous to floury endosperm in individual kernels. In Munck's procedure, highly sophisticated equipment is required which limits its application to basic research only. The Vicker's hardness tester can measure the hardness within individual endosperm cells (Munck et al. 1982).

Endosperm texture is related to various indices of grain hardness which have been developed using standard milling and sifting procedures (Maxson et al. 1971) or, alternatively, by recording the time required to dehull a standard quantity of grain to a specified level and recording the extent of breakage in the recovered endosperm (Oomah et al. 1981; Shepherd 1979). Although these measurements are subject to errors due to the interaction of grain shape with the abrasive mechanism, they seem to be quite reliable and are related to endosperm texture scores or breaking strength measurements taken with the Kiya rice hardness tester. Kernel shape affects the measurements taken with the kiya tester; flat and turtle beaked sorghum kernels frequently give erroneously high values (Murty and House 1980).

Selection Criteria for Breeders

Crop improvement programs generate a range of segregating material by making crosses between lines possessing good agronomic characters, disease and pest resistance, drought resistance, etc. These programs are confronted with the problem of choosing and advancing families which combine several economic characters, including food quality. Currently, there are no clear-cut methods to assist sorghum breeders to select for good food quality, as there are in wheat and rice breeding programs. Breeders in national or regional programs may select cultivars suitable for a particular product, while those in international programs may find it necessary to identify cultivars that are suitable to make a range of foods. Obviously, from the review made earlier, for most sorghum foods there is no clear identification of the physico-chemical properties of the grain that can be used to predict preferred quality, although several tests of possible significance have been reported. Simple tests tailored for laboratory use are urgently required to permit rapid progress in breeding for food quality in the developing countries.

An outline of a general scheme for quality testing in a breeding program is presented in Figure 2. Our experience indicates that considerable progress in quality breeding is possible by an empirical selection of the precise endosperm texture, while the food technologists and chemists continue research into the development of objective physico-chemical quality tests.

Selection in the F_2 generation should be for those grain characters which are controlled by major genes (Rooney and Miller 1982) such as colorless (rryy or R-yy?) and thin pericarp (Z-), absence of testa (b_1 b_1 or b_2 b_2), endosperm texture, and tan plant color (pp-). These characters could be selected by subjective methods in the field. A laboratory is not required. Where the sorghum crop is expected to mature towards the end of the rainy season, grain mold resistance is an important selection criterion. Grain quality characters, associated with the preferred food quality traits and mold resistance, may not necessarily be the same and the best recombinants which combine these two characters should be chosen. Grain of individual F_3 selections from the off-season crop could be used for laboratory tests of KOH color reaction. Since grain quantities might be limiting, samples from selections in the F_4 and F_5 generations might be used either for the study of gel viscosity or milling and flour quality. The evaluation of the qualities of the product per se needs to be done only on those entries which are selected for improved yield, adaptation, etc.

It is important that assessments on the food product be conducted with grain harvested in the main crop season for which the variety is intended. Consumer tests at the farmer's level should use only the most promising cultivars from

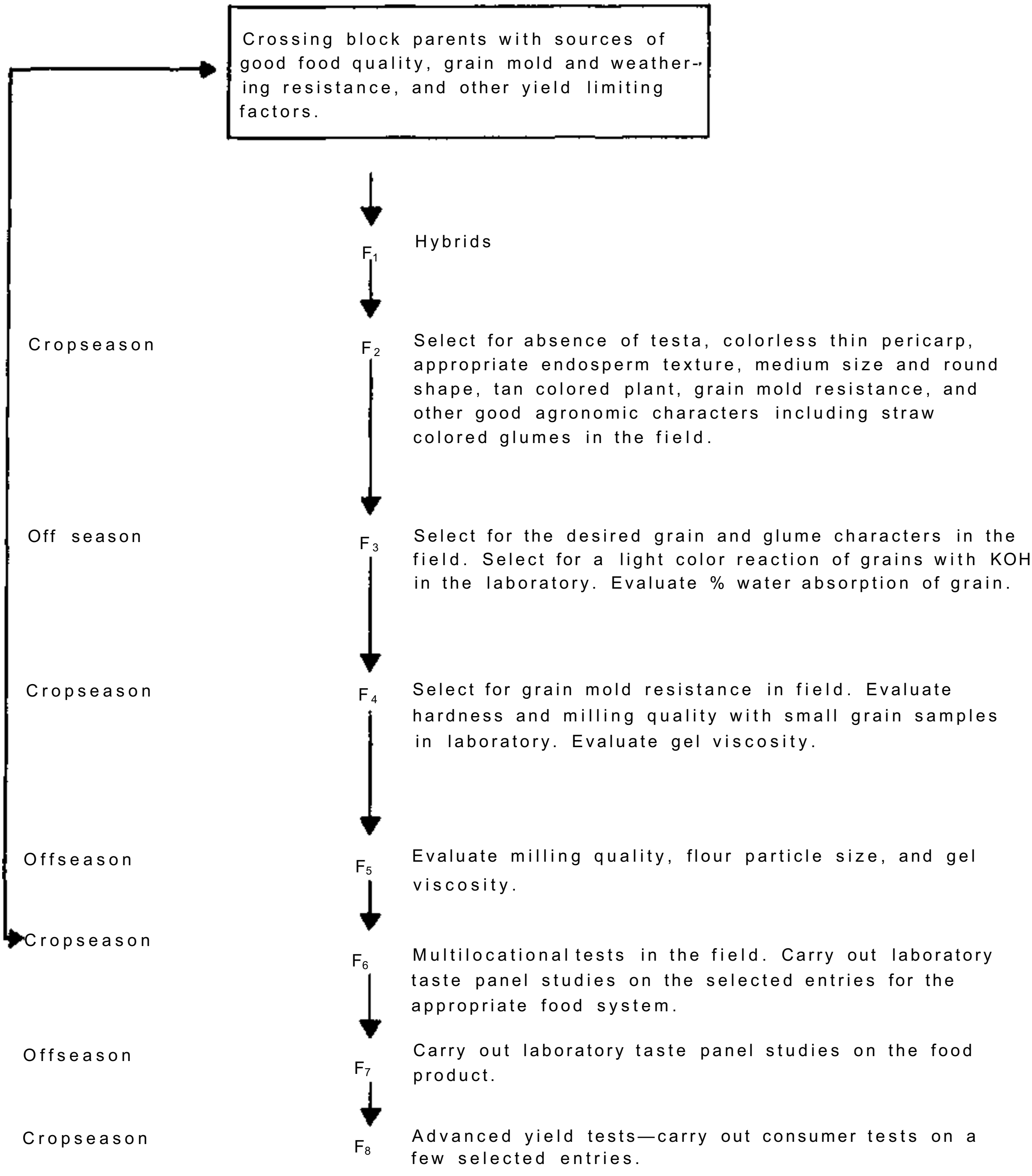

Figure 2. A proposed scheme for use in a breeding program to select for good food quality.

multilocation tests of yield and adaptation. The most preferred local varieties should always be included in these tests for comparison. This scheme could be modified to suit the major objectives of any breeding program involved in the improvement of yield-limiting factors like disease and pest resistance.

Food Technology and Sorghum Improvement

Future sorghum utilization can be increased most effectively through a combination of innovative new processing techniques along with-the development of sorghum varieties with characteristics that will be utilized most effectively in the new processes. New milling techniques have been developed recently (Reichert 1982; Munck et al. 1982). The successful development of small mills that will supply stable sorghum products to urban consumers will increase the acceptability of sorghum for foods. The improved milling processes will circumvent some undesirable features of sorghum and will affect the kernel characteristics desired. For instance, the best sorghum for milling will probably have a softer endosperm texture than currently desired which will save in processing costs because the soft endosperm can be more easily broken down into flour or desired milled products.

Effect of Industrial Use on Quality Attributes

In the future sorghum will increasingly be used for industrial processing into flour, grits, and other products which will be used for production of various foods using blends of maize, wheat, and other commodities (Rooney et al. 1980; Miche et al. 1977). This trend is currently under way. For example, sorghum grits are used widely in Mexico as an adjunct in the brewing of European types of beer(Aldape 1981) and a number of food products from malted sorghum are sold commercially in South Africa. Recently, in Central America some efforts have been made to replace imported oats with sorghum flakes as a breakfast food. The development and initial testing of "pearl durra" in the Sudan looks promising (Badi et al. 1981). Thus, although the actual use of sorghum in processed products is small, the interest and ability to make commercial products is advancing steadily.

The widespread industrial processing and use of sorghum will produce increased demands for higher quality sorghums, and quality will change as consumers adjust and become familiar with processed products. Novellie and co-workers have successfully scaled up the sorghum beer process from a small village process to a large-scale modem industrial procedure with the production in S. Africa of 3 million liters annually, which is equivalent to the European beer produced in S. Africa (Joustra 1981. personal communication). The local beer contains a significant amount of solids which contribute to the nutritional well-being of the consumer.

Currently consumers prefer sorghum beer that is light pink with a foam on top of the beer. This beer is made by using 10% sorghum malt that has been soured through lactic acid fermentation, which is mixed with 65% maize grits, cooked, and then mixed with 25% sorghum malt for converting the starch into fermentable sugars. Then, the mash is strained and fermented with yeast for 2-3 days and drunk while active fermentation is occurring. Because 65% of the cereal ingredients are maize grits, the beer has a light pink color with a slight foam on top. The reason the maize grits were used early in the industrial process was because inexpensive maize grits were available. Now sorghum is much cheaper than maize, but it is not possible to switch back to a 100% sorghum beer because the color is too dark and there is no foam. The population has now accepted the industrialized sorghum beer and evidently traditional sorghum beer of yesterday is not as desirable. Ironically, projects underway in S. Africa currently seek to process sorghum into refined grits that will produce sorghum beer with light color and the foam. Sorghum must be low in fat to produce a beer with acceptable foam properties. Clearly, similar changes in consumer preference will occur in other areas of Africa as industrialization of sorghum occurs.

Future of Sorghum for Food

Production of sorghum will remain high and probably expand in the future. Breeding of sorghum with careful concern for its quality will provide a useful grain for the new or modified technological processes that will emerge. The new processing systems will provide refined sorghum and millet products to urban consumers which will eliminate much of the daily drudgery that is now associated with postharvest technology of sorghum. Progress made in the past, especially in the last 5 years, is encouraging and suggests that in the 1980s we will meet many of these objectives. A major reason for our optimism is that many young scientists have been trained. Hopefully, they will spearhead the efforts to improve sorghums for food. Failure to do so will be a disaster for the world.

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Sorghum Nutritional Quality-Progress and Prospects

J. D. Axtell, Gebisa Ejeta, and L. Munck*

The aim of this symposium is to assess the current status of research on sorghum and to discuss prospects and opportunities for further research during the decade of the 1980s. Hulse, Laing, and Pearson (1980) have recently published an extraordinarily comprehensive and thorough review entitled "Sorghum and the Millets: Their Composition and Nutritive Value." Their introduction includes the following statement which we believe sets the stage for the presentation of this paper at this symposium. Hulse et al. (1980) state that "Sorghum and the principal millets, apart from their use in animal feeds, are the staple foods of many of the world's poorest people: people whose nutrient supply is invariably at risk. The nutritional quality of the grains should therefore be a matter of primary consideration for all those working towards their genetic and agronomic improvement."

We will review briefly the status of current research on nutritional quality of sorghum and then focus on prospects and opportunities for future research.

Basically sorghum contains just as high levels of the major nutrients—starch (68-73%) and protein (9-14%)—as the cereals which are considered the most nutritious. However, three major factors complicate the full utilization of this rich store of starch and protein.

First, protein and energy availability is limited in some sorghum genotypes by the presence of polyphenolic compounds (tannins) located primarily in the testa layer of the grain. These pigmented compounds are just recently being chemically characterized (Butler 1982) and are traditionally being referred to as "tannins."

Second, the protein quality of an all-sorghum diet is limited by the low lysine content of the grain which reflects the high prolamine content of the endosperm. If one looks at the essential amino acid composition of sorghum grain, in comparison with monogastric nutritional requirements, it is obvious that lysine is deficient and that there is a great excess of leucine in comparison with isoleucine, while there are no major deficiencies in the other essential amino acids. We will discuss two ways of solving the protein quality problem in sorghum, i.e., breeding for high lysine sorghum and dietary supplementation with proteins, for example from legumes.

Third, there are specific dietary limitations in the utilization of cooked and baked sorghum products for humans due to factors such as the high gelatinization temperature of the starch and the high viscosity of the cooked products leading to significant problems with regard to acceptability and digestion. To cope with these problems, local food preparation techniques have been developed often relying on specific local varieties. In the International Symposium on Sorghum Grain Quality (ICRISAT 1982) this interaction between food habits and sorghum varieties was described, for the first time, in a comprehensive way. Finally, we will also find that processing of sorghum could also be beneficial in animal nutrition.

Tannins

Butler (1982) has presented an excellent review of the biochemistry of sorghum tannins and polyphe-

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Table 1. Percent crude protein, 96 hr in vitro dry matter disappearance (IVDMD) and indigestible protein in eight sorghum genotypes.

Genotypes	Catechin equivalent	Crude protein	96 hr IVDMD	Indigestible protein residue
	% of dry matter			
IS0062	0.29	13.78	94.8a*	1.13
IS0418	0.27	12.11	93.1a	1.62
IS8165	4.28	11.26	88.8b	2.80
IS0616	5.93	14.20	83.0c	4.73

* Means in a column followed by the same letter do not differ significantly at the 0 05 level of probability using Newman-Keul's test.

nols and of the effects of polyphenols on sorghum grain quality. We will discuss some of his basic observations on the interactions between tannins and the nutritional value of sorghum grain in relation to our own research and to the scientific literature.

Oswalt first recognized that in vitro dry matter digestibility (IVDMD) of sorghum grains varied significantly between genotypes, and that the catechin equivalent values for tannin content were negatively correlated with IVDMD as shown in Table 1 (Schaffert et al. 1974). This was an extremely important observation because it explained the discrepancies which had previously been observed between protein quality and biological value in rat feeding experiments. Based on the amino acid composition of sorghum grain, one would predict that the biological value of any particular variety of sorghum grain would be directly proportional to its lysine content. This, in fact, is true for low-tannin sorghum genotypes. The data in Figure 1, however, illustrate that lysine is not the first limiting component of biological value for a group of high-tannin sorghum lines from the world collection. There is an important interaction between tannin content and protein quality in sorghum which is not found in any of the other major cereals. Cummings and Axtell (1973) demonstrated this experimentally by feeding whole grain and dehulled high-tannin sorghum grain of IS 8260, as shown in Figure 2. Rat growth is poor for the whole grain IS 8260, with and without supplemental lysine. In contrast, denuding IS 8260 grain improves biological value substantially, and also allows a significant rat growth response to the addition of supplemental lysine. A similar technique was used in this study to

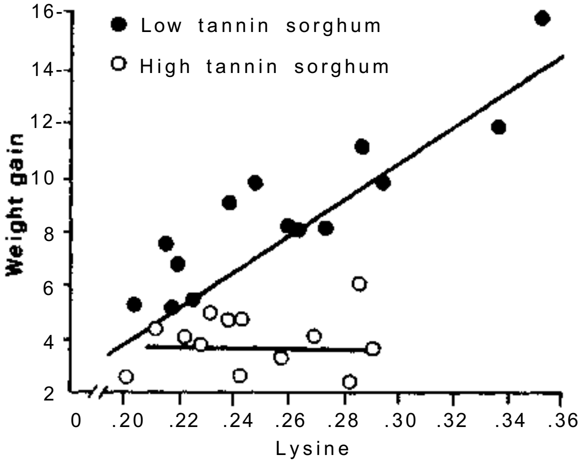

Figure 1. Relationship of biological value to lysine concentration (g/100 g sample) in high- and low-tannin sorghum lines from the world collection in a 14-day weanling rat feeding experiment.

determine the quantitative effects of tannins on biological value. Using varying proportions of high-tannin sorghum grain mixed with its dehulled low-tannin counterpart, we were able to provide diets containing a range of tannin content that were essentially isogenic comparisons. Data from this study are shown in Figure 3.

The protein digestibility and nutritional quality as measured by rat weight gain are significantly reduced by increasing levels of tannins in the diet. We can conclude from Butler's (1982) data that tannins bind specifically to proline residues in proteins and thus to the storage proteins (the prolamines) which are rich in proline but poor in

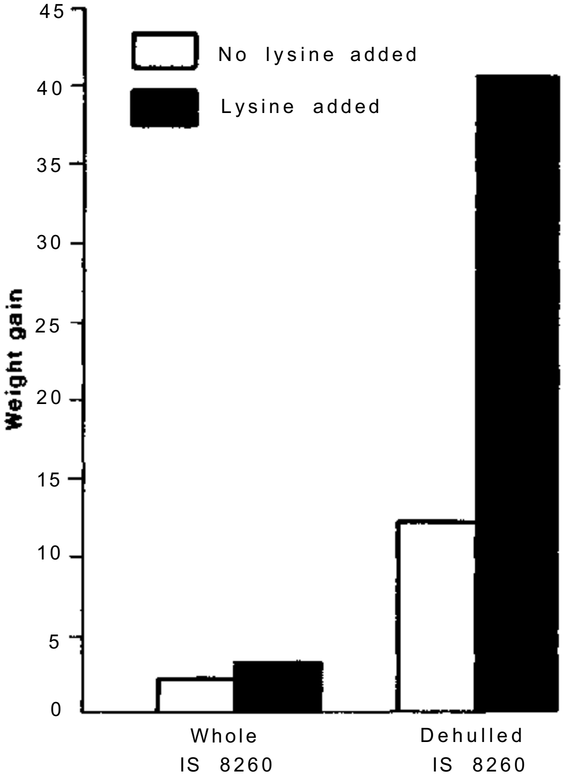

Figure 2. Biological value of whole and dehulled grain in high-tannin sorghum line IS 8260 when fed to weanling rats with and without lysine supplementation in a 14-day feeding experiment.

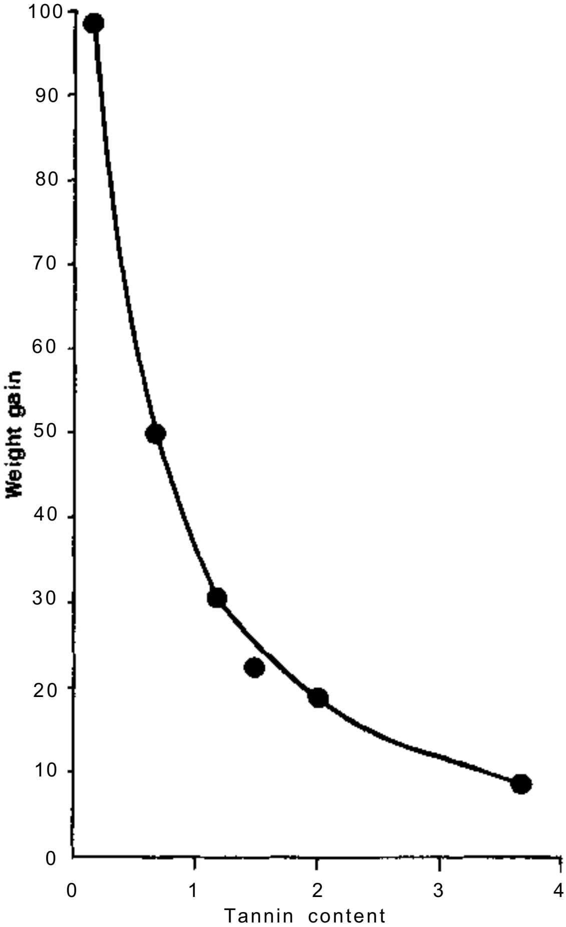

Figure 3. Effect of tannin content (expressed as catechin equivalents) on the biological value of sorghum grain in a 28-day weanling rat feeding experiment.

lysine. Nutritionally this binding leads to interesting effects. Thus in rat trials Eggum and Christensen (1975) found that the protein digestibility was reduced but the biological value (BV), defined as %N retained in the body of absorbed N , increased due to moderate levels of tannins. This is due to the selective binding of tannins to the low lysine prolamines which then become unavailable thus improving the amino acid composition of the proteins which are left for the rat to digest and absorb, finally resulting in an increase in BV.

It is very important to recognize the tannin interaction with protein quality when assessing the nutritional value of any grain sorghum variety, since failure to consider the biological effects of tannins has led to substantial confusion in past studies of sorghum nutritional quality.

Future progress in research on tannins will depend on a better understanding of the biochemistry of sorghum tannins and their interaction with seed proteins. Detoxification of sorghum tannins by alkali treatment seems clearly beneficial, which will be especially useful in animal feed utilization. Research on removal of tannins from the outer layers of the sorghum grain by decortication and milling will also provide an important future solution to the problem for grains to be utilized for human consumption (Munck et al. 1982).

Protein Quality

Two genetic mutants, one naturally occurring and one induced, have been identified that increase the lysine content of the sorghum endosperm and improve protein quality of the grain. A brief review of the origin of these mutants, and recent results of experiments on the relationship between improved protein quality and total grain production in sorghum, are presented.

Ethiopian High-Lysine Gene

Singh and Axtell (1973) screened about 10 000 entries in the World Sorghum Collection and identified two floury endosperm varieties from Ethiopia that contained a gene that significantly increased the level of protein in the grain and also increased the lysine concentration of the endosperm proteins. The screening process involved cross-sectioning seeds from each entry to identify those with floury endosperm phenotypes and then evaluating grain samples from those selected entries for protein and lysine concentration. Sixty-two floury endosperm lines were identified, of which two (IS-11167 and IS-11758) had a significantly higher lysine content than normal sorghum. These lines contain approximately 15 -17% protein in comparison with normal checks averaging about 12% protein. The lysine content of the Ethiopian high-lysine selections is approximately 3.1% (expressed as percent of protein) and 0.50% (expressed as percent of sample) in comparison with normal sorghum values of 2.0 and 0.26%, respectively (Axtell et al. 1974). The nutritional quality of the Ethiopian high-lysine grain is also significantly higher than normal sorghums in isonitrogenous rat feeding experiments (Singh and Axtell 1973). It has been established that the concentration of alcohol-soluble proteins is significantly reduced in high-lysine endosperm, relative to values present in normal sorghum endosperm (Jambunathan et al. 1975).

Utilization of High-Lysine in Ethiopia

A collection trip was made in 1973 to determine whether the high-lysine varieties identified in the World Collection were being cultivated by farmers in Ethiopia. The lines originally identified from the World Germplasm Collection were obtained in Wollo Province in the central highlands of Ethiopia. Farmers continue to grow these varieties in mixed plantings of sorghum varieties in this area of Ethiopia. A large number of varieties similar to the original high-lysine variety was collected in addition to an equivalent number of normal varieties for comparative purposes. Ejeta (1976) has evaluated the protein and lysine content of grain from high-lysine and normal varieties grown under actual field conditions in Ethiopia. Figure 4 illustrates the lysine and protein concentration in this series of high-lysine and normal sorghum varieties. The mean lysine concentration, expressed as percent of protein, was 2.88 for the high-lysine entries and 2.17 for the normal sorghum varieties grown in the same environment. Protein values were 15.7 and 11.4%, respectively. It seems likely that the high-lysine gene has been present in Ethiopia for a long period of time, since there is a great diversity in panicle morphology, maturity and plant height among the high-lysine genotypes collected. The farmers roast the heads qf the high-lysine varieties in the late dough stage and eat the grain in mixtures with grain from normal sorghum varieties prepared in a similar way. There is a general recognition by the farmers that the yield of high-lysine varieties is significantly less than normal varieties. Gebrekidan has estimated (Table 2) that the high-lysine cultivars grown in Ethiopia yield approximately 72% of normal check varieties (Gebrekidan, personal communication). The reason given by the farmers for growing these varieties is that the high-lysine grain has superior flavor and improved palatability when roasted.

There is a good opportunity to utilize these high-lysine varieties in African countries as high-protein, special-purpose sorghum varieties. The protein concentration is increased by about 30%, along with the significant increase in protein quality. The grain from these varieties is recognizably different for marketing purposes because of the somewhat dented kernel phenotype of the mature grain. The flavor characteristics also appear to make these varieties quite acceptable for human consumption. We propose that these Ethiopian high-lysine varieties should be utilized in rural populations as special-purpose sorghums for people who have a high protein requirement. It should be possible for farmers in rural areas to produce an adequate quantity of high-lysine sorghum grain on a small section of their farm for use as a weaning food and a supplement for pregnant women and nursing mothers. It may also be possible to develop a marketing system whereby these grains can receive a market premium when sold in the cities.

Chemically Induced High-Lysine Mutant

Mohan (1975) utilized chemical mutagenesis to

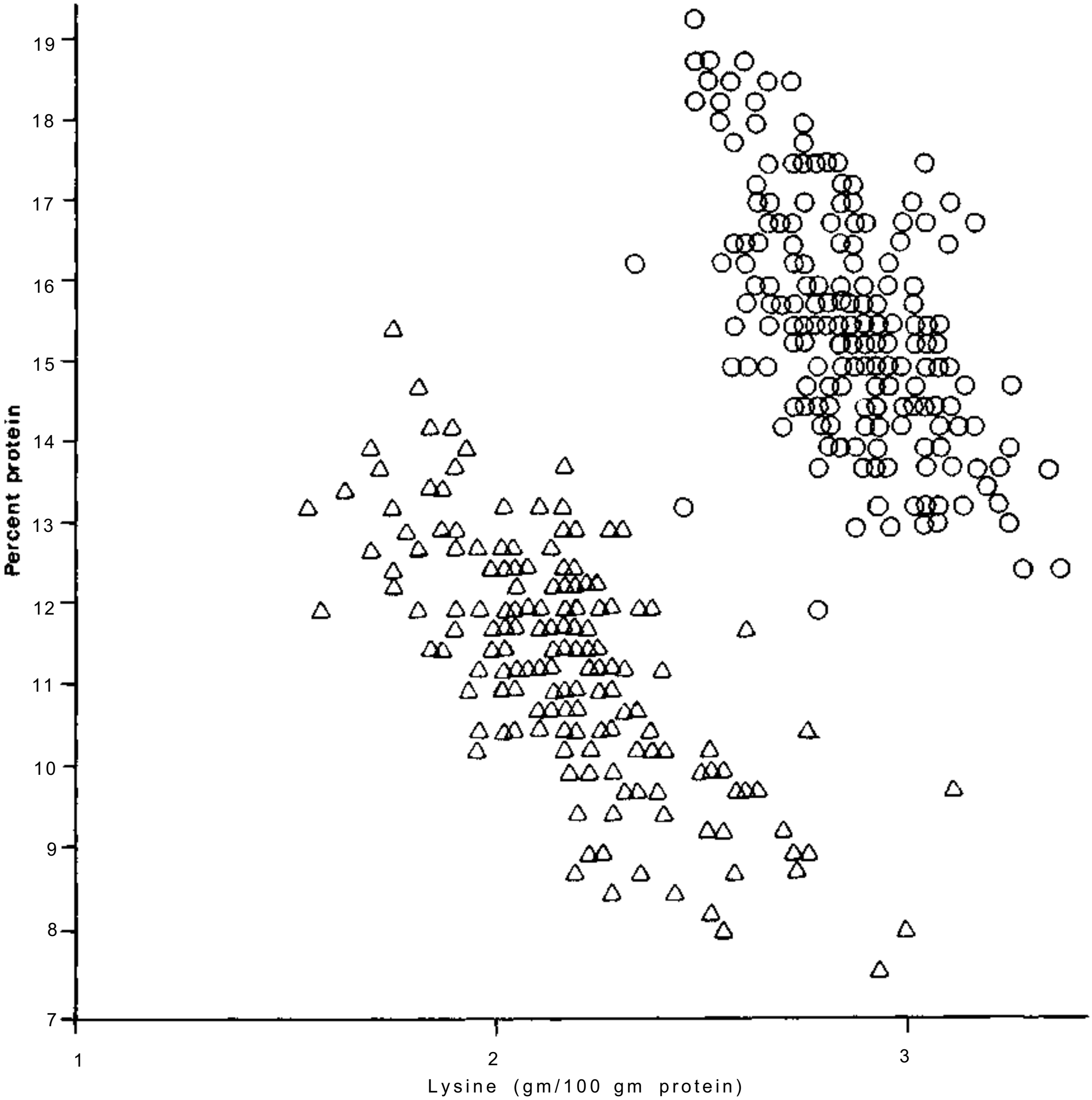

Figure 4. Relationship of protein and lysine in normal and high-lysine sorghum lines collected from the same environment. Circles represent data from dented high-lysine varieties; triangles represent data from plump normal cultivars collected in the same geographic region.

induce a second high-lysine gene mutation in sorghum. The parent line used for the mutagen treatment was a photoperiod insensitive, three-dwarf sorghum line with relatively broad agronomic adaptability. The parent line also had a colorless pericarp and a translucent (vitreous) endosperm so that progeny from the mutagen treatments could be screened for opaque mutant kernels over a light box. Selfed seed was treated with diethyl sulphate (DES) by soaking in a solution containing 1 ml DES per 1000 ml of

Table 2. Mean grain yields of 12 high-lysine sorghum cultivars and 2 check cultvars evaluated at Alemaya, Ethiopia.

	Grain yield (t/ha)		
Sorghum type	1975	1976	Mean
High-lysine	2.0	2.5	2.3
Normal	2.9	3.5	3.2

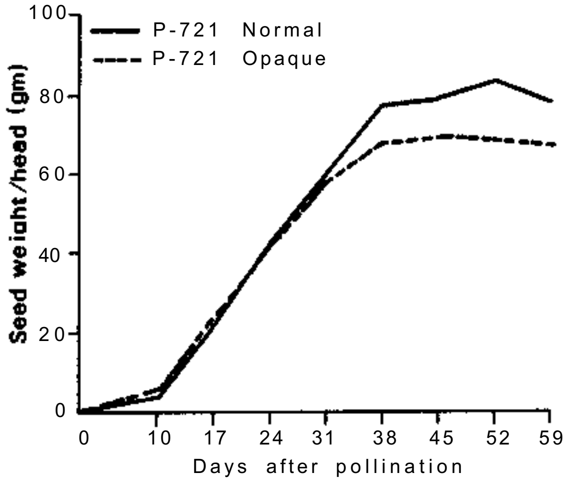

Figure 5. Mean increase in seed weight per head of P-721 opaque and P-721 normal sorghum during grain development in a space-planted population.

distilled water for 3 hr. The M_1 plants were grown in Lafayette, Indiana. USA during 1972 and each head was bagged to ensure self-fertilization. M_2 plants were then grown in Puerto Rico during the winter of 1972-73 and each M_2 head was again bagged to ensure self-fertilization. Approximately 23 000 bagged M_2 heads bearing M_3 seeds were harvested in the spring of 1973 in Puerto Rico and shipped to Lafayette for evaluation.

Seed from each head was threshed and examined for opaque kernel segregates over a light box. A total of 445 putative opaque mutants were identified and seed from each segregating head was separated into vitreous and opaque classes. Both classes of seed from each putative mutant head was then analyzed for protein and lysine concentration. Of the 445 mutants, only 33 were identified that had an increase in lysine concentration greater than 50%. Plants from each of these 33 opaque and normal sib seed lots were grown in paired rows to evaluate them for any morphological changes associated with the change in endosperm phenotype. Most of the opaque mutants were found to drastically affect either plant or seed development. Only one of these 33 (P-721) was found to produce normally appearing plants and seeds. The P-721 opaque mutant produced an increase of about 60% in lysine concentration. The mutant is controlled by a single gene that is simply inherited as a partially dominant factor. The nutritional quality of P-721 grain is significantly higher in monogastric feeding experiments than normal sib counterpart grain (Mohan 1975).

VanScoyoc (1979) has examined dry matter accumulation during grain development to determine what effect the P-721 mutant has on grain yield potential. Figure 5 presents the mean seed weight per head of P-721 opaque and normal sib heads at periods ranging from 10 to 59 days after pollination in a space-planted population. It is evident from these data that there is no difference in dry matter accumulation until approximately 31 days after pollination. After 31 days, dry matter accumulation in the P-721 opaque line levels off, whereas dry matter in the normal sib line continues to accumulate for an additional week, plateauing at 38 days after pollination. VanScoyoc has also examined 1000-seed weight during grain development and his data are presented in Table 3. Seed weights of the normal and opaque lines are similar at 31 days after pollination, but diverge at 38 days after pollination. At maturity, kernel weight for the opaque line is reduced by 11 - 14% relative to its normal counterpart. No reduction in seed number was observed, so the difference between the lines can largely be accounted for by reduced kernel density. The reduction in kernel weight is in relative agreement with preliminary data from a 1977 four-replicate yield trial at 147 664 plants/ha showing a 9.4% total yield reduction for P-721 opaque compared with its normal sib line.

Yield of P-721 Derived Lines

The next phase of this sorghum improvement program involved the making of hundreds of crosses of the P-721 opaque mutant with high-yielding entries from the World Sorghum Collection, with elite lines from the Purdue/AID sorghum breeding materials, and with individual plants selected from genetically heterogeneous random mating populations. Emphasis was put on incorporating the P-721 opaque gene into many and diverse genetic backgrounds to enhance the probability for identifying a genetic background which was optimal for expression of the P-721 gene. The pedigree breeding procedure was used in handling progenies from these crosses. Early generation selections were evaluated for agronomic desirability and yield potential at Lafayette, Indiana, USA, and for tropical adaptability in Puerto Rico. All segregating lines which lacked promising agronomic potential were discarded

Table 3. Mean 1000-seed weights of P-721 opaque and its normal sib line during grain development in a space planted population.

Days after pollination	1000-seed dry weight (g)[a] P-721 normal	P-721 opaque	% P-721 opaque of normal
17	7.625	7.875	103.3
24	14.664	14.294	97.5
31	18.562	18.998	97.7
38	23.164	21.652	93.5
45	25.455	21.608	84.9
52	24.099	21.451	89.0
59	24.861	21.358	85.9

a Mean of three replicates.

without attention to chemical evaluation because the major objective was to derive high-yielding, agronomically desirable sorghum lines in which the P-721 gene had survived. Some 197 homozygous opaque F_6 lines survived and after a final screening against lodging, stalk rot, and foliar diseases in Puerto Rico, VanScoyoc (1979) tested the best 158 lines, 11 elite normal cultivars from international trials, and RS 671 for yield (Fig. 6). Several of the elite normal lines (the P-954 series) have yielded very well in Africa.

Yields of the 158 P-721 lines and the 11 elite normal lines were divided into three classes: 22 with low yield, 111 with intermediate yield, and 36 with high yield. All check lines were in the high-yield class. Among entries that yielded above 8.0 t/ha, the 12 opaque lines and the 7 vitreous controls gave mean yields of 8.5 t/ha. Among entries yielding above 7.6 t/ha, the mean for 24 opaque endosperm lines was only slightly less than that for the 12 checks (8.1 vs 8.2 t/ha, respectively). These data indicate that lines with the P-721 opaque gene can yield as well as the best normal sorghum cultivars if the gene occurs in the proper genetic background. Earlier, Christensen (1978), by studying a subset of the P-721 lines in F_5 breeding lines, also showed that the P-721 opaque gene when placed in an appropriate genetic background would not reduce grain yield potential (Table 4). Because seed weight was reduced about 15% by the P-721 opaque gene, we speculate that selection for grain yield in P-721 lines must have resulted in an increase in the number of seeds per panicle and/or the number of panicles per unit area in order to have maintained a good yield level (Axtell et a). 1979). It is likely that variations in sorghum panicle morphology allows compensation for reduced seed weight by increasing seed numbers per panicle.

Acceptance of high-lysine sorghum cultivars will be limited by problems associated with the opaque kernel phenotype. Ejeta (1979) was successful in identifying several lines with vitreous endosperm and high lysine content. Subsequently, these proved to be stable for vitreous endosperm phenotype and high lysine concentration. Also, seed treatments of P-721 opaque, high-lysine sorghum lines with DES resulted in mutants with vitreous endosperm and high lysine concentration (Porter 1977; Ejeta 1979). In general, the lines with modified vitreous endosperm from both sources had higher kernel weight and lower percentages of protein and lysine (Table 5). Also, the most vitreous types had the highest test weight.

A replicated yield trial of 35 opaque lines and 11 normal lines at two locations in Indiana has recently been completed. The results are presented in Table 6. The mean grain yield of the top three P-721 opaque lines is similar to that of the top three normal checks in the trial. The dye binding capacity (DBC) of the high yielding P-721 derived lines is intermediate between the checks and that of the original P-721 opaque line.

Future studies with regard to the food-making characteristics of the high-lysine lines will reveal new possibilities and drawbacks. Thus we can await that the milling quality of the more vitreous

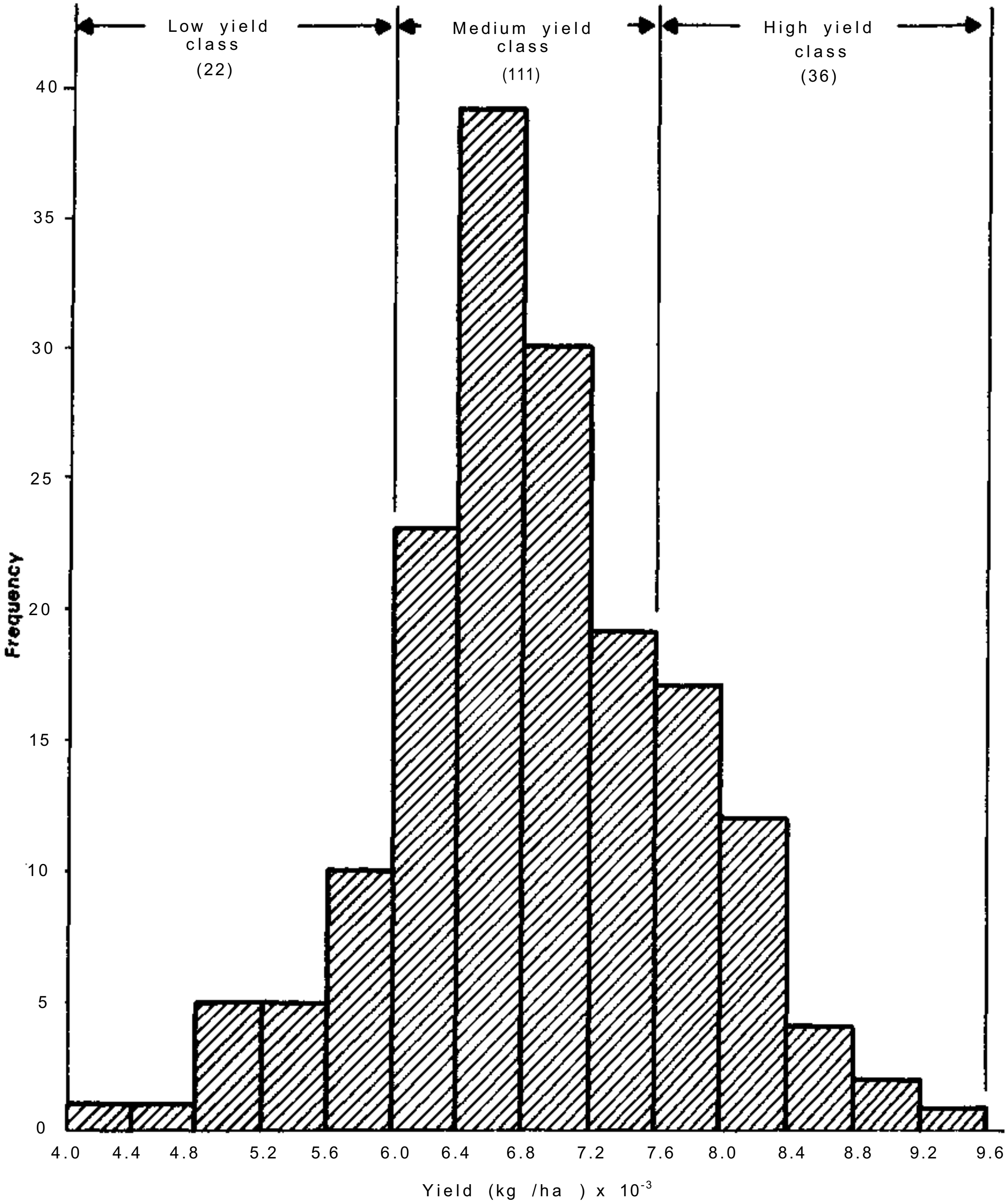

Figure 6. Frequency distribution of grain yields of F_7 P-721 opaque-derived lines and elite normal cultivars of sorghum.

high-lysine lines previously discussed will have better milling characteristics than P-721 opaque which is poor in milling quality due to its softness.

Dietary Limitations

Recently, nutritionists at the Johns Hopkins University have conducted a series of experiments

Table 4. Means of chemical and agronomic traits for opaque, heterozygous, and normal grain types In P-721 derived lines and high-yielding checks of sorghum.

Genotype or cultivar	No. of entries	Dye binding capacity	Protein (%)	Yield (t/ha)	100-seed weight (g)
P-721 Genotype					
Opaque	300	49.3	12.5	4.7	2.50
Heterozygous	73	42.5	13.3	4.5	2.89
Normal	5	39.8	12.9	4.2	2.87
Checks					
954063 (cultivar)	4	34.0	11.4	5.7	258
RS-671 (hybrid)	4	34.3	11.7	5.6	2.30
NK-300 (hybrid)	4	33.8	10.9	6.7	2.18

Table 5. Protein and lysine contents and 100-kernel weight for vitreous (modified) and opaque endosperm kernels from lines derived from P-721 high-lysine sorghum.

Endosperm type	Protein (%)	Lysine (% of protein)	100-kernel weight (g)
Modified	11.3	2.77	2.56
Opaque	12.6	2 83	2.27
Modified as % of opaque	90.0	97.90	112.80

Table 6. Mean grain yield of P-721 opaque derived lines in comparison with normal checks and original P-721 opaque mutant line

	Fl* (Days)	Ht** (cm)	Yield (kg/ha)	% Protein	DBC***
High-lysine entry					
851171	81	145	8472	9.00	35.50
850029	82	130	8221	9.07	35.00
851356	82	155	8158	8.56	34.75
Mean	82	143	8284	8.88	35.08
Check entry					
954206	85	205	8660	7.68	29.75
954062	81	180	8284	9.32	31.50
954063	81	140	8158	8.86	29.75
Mean	82	175	8346	862	30.33
P-721 opaque	81	125	5585	9.92	42.75

* Fl = Days to flowering.
** Ht = Height at flowering.
*** DBC = Dye binding capacity.

Table 7. Comparison of results from nitrogen balance studies in sorghum with similarly obtained corresponding data from other staple foods.

	Apparent N balance		Stool weight		
	Absorption %	Retention %	Wet (g/day)	Dry (g/day)	Stool energy (Kcal/day)
Sorghum	46	14	224	39.0	183
Wheat	81	20	95	13.3	60
Rice	66	26	67	11.6	58
Potato	66	34	165	20.3	78
Maize	73	27	133	268	117
Casein	81	38	95	15.5	63

involving children in Peru using all staple food diets based on gruels made of sorghum, maize, wheat, rice and potatoes. Their results indicate that whole grain sorghum is "markedly inferior" to wheat, rice, potato and maize as a source of dietary protein and energy in diets unsupplemented with proteins and amino acids fed to children. MacLean et al. (in press) thus conclude, "whole grain sorghum is a bulky and poorly digestible source of dietary energy for children." Table 7 summarizes the results of 26 dietary sorghum periods in comparison with corresponding data from other staple foods. The poor absorption (46 ± 17%) and retention (14 ± 10%) of nitrogen and the high content of energy in the stools from sorghum made it, in this experiment, a very poor source of dietary protein. Maize was intermediate between sorghum and the other staple foods in energy digestibility as measured by the stool energy. Sorghum was associated with a dramatic slowing of the rate of weight gain in these experiments, which presumably resulted from excessive fecal energy losses and as a response to inadequate quantity and quality of dietary protein. The return to the control diet was associated with a prompt resumption of weight gain and a rebound in apparent nitrogen retention, the latter being further indicative of protein inadequacy during the sorghum period.

All sorghum diets based on sun dried powders of traditional Tanzanian food products fed to rats (Table 8. Eggum et al. 1982) also display extremely low weight gains and low biological value (BV) of protein as measured in balance trials. Lysine is extremely low (2.0%) in the raw material and decreases markedly in the hand decorticated product (1.2%) while *ugali* porridge cooked on the whole grain seems to be more nutritious (weight gain 1.40 g/day) than the porridge from the decorticated grain virtually producing zero growth. It is seen in Table 8 that the rats could not cope with the food intake in the most lysine deficient diets indicating an increased strain on the animals. However, the protein and energy digestibility in these trials were quite high (about 90%). Eggum et al. (1982) concluded that the performance of the rats on sorghum diets in this trial fundamentally was due to the low level of lysine. Although it is difficult to compare feeding experiments from different organisms such as rat and man, two major factors could be hypothesized to explain these results.

First, dietary factors such as starch/protein availability could affect the sorghum digestion especially in the experiment with children fed the diet as a gruel. Second, the low lysine content of these diets would call for supplementation with properly balanced protein, e.g., milk. A search was made at Purdue for an in vitro system sensitive to the digestibility differences between sorghum and other cereals. Axtell et al. (1981) found that porcine pepsin in vitro shows these digestibility differences. The results in Table 9 show that uncooked sorghum proteins have a high pepsin digestibility (78-100%), which drops to a range of 45-55% after cooking. It is therefore essential that more research be conducted to determine the nutritional consequences of local methods of preparation of sorghum foods in countries in Africa, Asia and Latin America. It is assumed that the most sophisticated methods of food preparation would have evolved in areas of the world where sorghum has been used for the longest period of time, i.e., the center of origin of the crop

Table 8. Nutritional quality of the improved low-tannin sorghum variety, 2Kx17/B/1, as processed in Tanzania. Rat balance tests according to Eggum et al. 1982.

	Weight gain (g/day)	Feed consumed (g/day)	Biological value (%)	Lysine (g/16g N)
1. Whole grain	1.26	97	55.9	2.0
2. Laboratory *ugali* whole grain	1.40	9.8	55.7	1.9
3. Hand decorticated in Tanzania	055	63	47.4	1.2
4. *Ugali* from (3) cooked in Tanzania	004	6.1	49.4	1.2

Table 9. Effect of temperature on digestion of sorghum proteins by pepsin.

	Whole kernel*		Dehulled kernel*	
Variety	Uncooked	Cooked	Uncooked	Cooked
IS-11758 high-lysine	88.6	45.3	78.2	41.4
954063 normal	88.9	50.6	81.7	37.1
P-721 opaque	93.0	56.7	85.7	43.0
P-721 normal	92.9	46.4	81.1	40.7

* Percent solubilized by pepsin Average of duplicate values

(Ethiopia and Sudan). Results of pepsin digestibility studies of some Sudanese sorghum breads are now complete and show clearly that local processing (fermentation to pH 3.8) significantly improves in vitro protein digestibility of sorghum proteins. Two fermented sheet-baked sorghum products (*kisra and abrey*) from Sudan gave pepsin digestibility values of 65-86% (Table 10). In contrast, unfermented cooked gruels made in our laboratory from the same flours using the Johns Hopkins cooking technique gave pepsin values of only 44-56%. Therefore, fermentation improves pepsin digestibility of sorghum proteins. Experiments on rats with similar diets (Eggum et al. 1981) points in the same direction as the in vitro studies although the differences are less in vivo. Thus addition of acid to pH 3.8 while cooking porridge from Feterita sorghum reduces the drop in true digestibility of protein due to cooking from 13% to nil. Sorghum-based fermented infant foods (*nasha)* are currently being prepared for trials with children in Peru and Sudan, in cooperation with Food Research Institute in Khartoum.

The biochemical basis of the reduced nutritional value of some sorghum-based foods remains unknown. One possibility being explored is related to the protein solubility fractionation patterns observed in sorghum versus other cereals. Nwasike et al. (1979) showed that Landry-Moureaux fraction III in sorghum comprises a much larger proportion of the total prolamine proteins in sorghum than in corn or pearl millet (Table 11). Guiragossian et al. (1978) first demonstrated the high proportion of cross-linked kafirins (fraction III) in sorghum endosperms from both normal and high-lysine grains (Table 12). The possibility exists that the cross-linked kafirins in sorghum are involved in the formation of complexes with starch during cooking which then reduces availability to digestive enzymes. It would be extremely useful to have a sorghum mutant with reduced fraction III kafirins to test this hypothesis, but none are available at this time.

It is concluded from our present knowledge that monotonous sorghum diets are especially detrimental to growth and health and need supplementation with adequate protein sources such as legumes. Pushpamma et al. (1979) demons-

Table 10. Effect of fermentation and temperature on digestion of sorghum proteins by pepsin.

Variety	Protein (%)*	Uncooked**	Laboratory cooked**	*Kisra***	*Abrey***
Dabar	8.7	100.0	55.7	65.4	86.2
Tetran	9.0	91.4	46.7	76.0	-
Mayo	9.1	73.1	43.6	-	71.1

* Protein contents of Dabar *kisra.* Dabar *abrey.* Tetran *kisra,* and Mayo *abrey* were 114. 12.4. 10 4 and 8.7%. respectively.
** Percent of protein solubilized by pepsin. Average of duplicate values.

Table 11. Nitrogen distribution in the Landry-Mouraaux (LM) fractions of pearl millet, maize, and sorghum normal whole seeds.

LM fractions	% of total N		
	Pearl millet	Maize	Sorghum
I albumin-globulin	22.3	16.6	10.0
II true prolamine	41.4	38.6	15.7
III prolamine-like	6.8	10.1	31.3
IV glutelin-like	9.3	10.0	4.5
V true glutelin	20.9	20.2	29.3
Total N extracted	100.7	95.5	90.8
% protein in seed	14.3	10.7	13.5

trated in experiments with young children that sorghum gives an acceptable protein digestibility as well as nitrogen retention in mixed diets with legumes. The results were almost as good as with a rice/legume mixture. These results indicate that sorghum contains potentially rich sources of carbohydrates and proteins which can be utilized only if proper supplementation with other protein sources can be provided.

Conclusions and Future Research

Studies of the nutritional value of sorghum grain for human nutrition are only beginning and the data accumulated so far are not adequate because too little work has been done with the locally produced food products. The enormous body of data from animal nutrition with unprocessed sorghum strongly suggest that, with the exception of high tannin grain, the response of swine and poultry as well as rats fed sorghum grain is the same or slightly less efficient than the response from other feed grains such as maize. With ruminants a definite positive effect is seen with heat treatment (micronizing) or steam flaking of sorghum grain, again pointing out sorghum's uniqueness in its compact physical structure which for several purposes has to be overcome by proper processing and cooking.

We also know that human populations have survived and indeed flourished on sorghum-based diets for hundreds or thousands of years. The difficulties encountered in sorghum utilization have been counteracted by locally developed food preparation practices such as decortication and acid and alkaline treatments, fermentation as well as supplementation with other plant products, the nutritional importance of which we are just beginning to understand.

In the light of these observations, it is natural that we should be concerned about the nutritional quality of sorghum. The more information we have on the nutritional quality of sorghum, the more appropriately can we use this cereal grain in

Table 12. Nitrogen distribution in *sorghum* endosperm*.*

Fraction	Variety		
	P-721-Normal	P-721-Opaque	IS-11167
Percent protein (g/100 g of endosperm)	12.0	10.6	10.5
I (albumins and globulins)	9.0	28.6	23.1
II. (kafirin)	25.1	9.9	10.7
III (cross-linked kafirin)	25.1	15.3	19.0
IV (glutelin-like)	6.8	4.1	4.8
V (glutelin)	34.0	42.1	42.4
Total N extracted, %	98.6	97.9	91.4

* Percent of soluble nitrogen

the future, both for feed and food. The incentive to increase sorghum production by breeders, pathologists, entomologists and others will depend in part on our ability to profitably utilize the increased amounts of grain produced. For example, if it becomes possible to detoxify tannins in sorghum grain by inexpensive alkaline treatment (Butler 1982), the market for grain sorghum as a poultry feed in the Southeastern United States will predictably expand, since predatory birds and molds are a major deterrent to sorghum production in this area. Similar opportunities would exist in other parts of the world. This will only be possible through detailed biochemical and animal nutrition studies which identify the polyphenols in sorghum and define the mechanism(s) of their anti-nutritional effects.

Protein quality research needs to be continued to determine what level of success is achievable without sacrificing grain yield or food grain quality. Here a distinction needs to be drawn between plant breeding *research* objectives and plant breeding objectives. Protein quality improvement in sorghum remains a *research objective* at this time and is not a goal for most developing country sorghum breeders to pursue. We remain convinced, however, that in the near future we will be able to offer methods for genetic improvement of protein quality in sorghum without sacrificing either grain yield or food grain quality. A very substantial research effort on the molecular genetics of seed storage proteins is in progress throughout the world. Based on the knowledge and techniques gleaned from these studies we are confident that we will learn how to manipulate plant genes to design endosperm storage proteins to better meet human nutritional needs.

A great deal of research is needed to resolve the often conflicting results on human digestibility of sorghum proteins. It is imperative that the human nutritional evaluation be conducted in consort with cereal chemists and food scientists who can duplicate local village procedures used in sorghum food preparations. It is also important to develop centers for nutritional studies, e.g., in Africa, so that the response of African children to their own traditional foods can be measured.

The complementarity of other foods in the diets of people using sorghum as the staple cereal must also be considered in the overall nutritional evaluation. Recently in Egypt we noted that fenugreek, a small seeded grain legume, was frequently mixed as ground flour with sorghum flour, as 5% of the mixture. The fenugreek flour in the mixture added elasticity to the sorghum dough as much as gluten protein does in wheat dough. The fenugreek added significantly to the protein quality of the Egyptian sorghum bread since our analysis showed it to contain 28% protein and 6% lysine (expressed as percent of protein). If this lysine from the fenugreek is physiologically available, it also improves the utilization of the sorghum proteins. Experiments are in progress to test this point. Certainly many other legumes are regularly used as complements to sorghum as well as other cereal diets, but we know relatively little about their effect on protein and carbohydrate utilization. Much research is needed in this area.

The high in vitro protein digestibility of the fermented Sudanese *kisra* and *abrey* strongly suggest that local food preparation methods have evolved which improve the nutritional quality of sorghum grain. These results are confirmed in vivo in rats (Eggum et al. 1981) but we suspect that this result may represent only the tip of the iceberg with regard to the interaction between village processing of sorghum and the nutritional value of the prepared foods. Again, a great deal of research is needed including nutritional studies on humans in the decade ahead.

The ultimate objective of research on nutrition and utilization studies in sorghum is to enhance the acceptability of sorghum grain as a human food, and to increase the versatility of this cereal which offers so much potential to people living in the semi-arid regions of the world. Certainly we have gained much knowledge about sorghum quality during the 1970s, and in our opinion the momentum for such studies is increasing. Research is the key to understanding, and understanding is the key to further progress in the eighties.

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Sorghum as an Energy Source

R. E. Schaffert and L. M. Gourley*

The use of sweet sorghum for energy production, principally ethanol production, is discussed. An example of an integrated food, feed, energy, and biofertilizer system is presented. As sorghum is one of the most efficient plants in terms of photosynthesis and as sorghum directly produces fermentable sugars as well as grain, it is one of the most ideal crops for the simultaneous production of energy and food. The industrial by-products can be used as feed, biofertilizer, fiber, and energy. Technology for ethanol production adapted from the sugarcane industry can be utilized almost directly to produce ethanol from sweet sorghum. The additional adaptation of this technology for use in a microdistillery allows for economical small-unit production in a decentralized industry. Transportation costs are reduced and the alcohol is generally consumed by the producer. The process can be completely mechanized or not, depending upon the need to generate jobs and the cost of labor. Production levels have been considered and research recommendations for this decade have been made.

Energy Crisis

Since 1973 when the petroleum cartel OPEC, initiated a series of price increases and more recently with mounting political instability among several OPEC members, much emphasis has been placed on alternate and renewable energy resources and energy independence. Energy prices have increased considerably and energy, principally liquid fuels, has been rationed or considerably taxed to reduce their use in nearly all the petroleum importing nations. This has modified the economies of nearly all the nations of the world and has increased food costs in general, and frequently reduced food and feed production, making it more costly and difficult to feed the world's millions, especially the world's hungry.

Biomass

In many parts of the world, especially the developing nations, one alternative to the energy crises is the production of bioenergy from biomass. In the tropical and subtropical areas, and to a lesser extent the temperate areas of the world, an integrated food, feed, biofertilizer, and energy production system using sweet sorghums [*Sorghum bicolor* (L.) Moench] and high energy sorghums (Miller and Creelman 1980) along with other crops appears to be an economical and logical response for adequate food and energy production.

This paper will concentrate on the aspect of sorghum as a renewable resource for liquid fuel or ethanol production and treat to a lesser degree some possible integrated food and energy systems.

Ethanol—A Renewable Energy Resource

Ethanol has been produced by man since early recorded history as a constituent of fermented beverages. Ethanol as a liquid fuel was used in the earliest automobiles. Henry Ford's early automobiles had carburetors that could be adjusted to use either gasoline or alcohol. Since the early 1900s Brazil has used ethanol mixed with gasoline to utilize surplus alcohol from the sugar industry

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and during the World Wars ethanol was used in place of gasoline.

The attractions of alcohol for fuel are many. The world's oil reserves are concentrated in just a few countries, while the potential for producing alcohol from energy crops is as widely diffused as agriculture itself. Liquid fuel from biomass is a renewable resource. Alcohol as a fuel is clean-burning when used alone and when mixed with gasoline it acts to increase the octane rating. Energy crops production and alcohol distillation will require more labor than oil production and refining and thus aid unemployment problems and mass migration to the cities. Because of the transportation limitations of sugar crops, distilleries will be decentralized and dispersed throughout the crop production area.

Alcohol fuel has a powerful political appeal to governments and the common motorist. The problem of balance of payments, possible oil supply disruptions, and rising gasoline prices promote political action toward self-sufficiency. In the United States, which has 40% of the world's automobiles and which uses half of all the gasoline consumed in automobiles, political pressures to produce liquid fuels domestically are particularly strong.

National Energy Policies

Among the countries already producing ethanol for fuel. Brazil is the unquestioned leader. Brazil's alcohol fuel program was launched in 1975. The goal to become self-sufficient in automotive fuel by the end of the century has been upgraded to the end of the eighties. Government incentives include financing to help modernize and expand existing alcohol distilleries, to build new distilleries, and to develop agricultural projects to supply them with feedstock. The national alcohol fuel program is based principally on sugarcane, but also emphasizes sweet sorghum and cassava as distillery feedstock. In 1981 /82 Brazil will produce approximately 5 billion liters of ethanol and the target is 11.5 billion liters by the end of 1985. In 1981 the Brazilian Government officially approved the extablishment of microdistilleries with a capacity of up to 5000 liters of alcohol/day. The government's goal is to install 5000 microdistilleries by 1985. These microdistilleries, which function most economically using both sugarcane (6 months) and sweet sorghum (4 or 5 months) (Fig. 1) for a total of 10 or 11 months per year, will be scattered throughout Brazil and the alcohol will be consumed in the locality in which it is produced.

The first United States alcohol fuel program came with the enactment of the Energy Act of 1978. This legislation removed the federal gasoline tax of four cents on every gallon of gasohol, provided the alcohol used in the blend was from nonpetroleum sources. Many states have also made gasohol tax exempt which when combined with the federal exemption amounts to a total subsidy of more than $1 per gallon for ethanol used as automotive fuel.

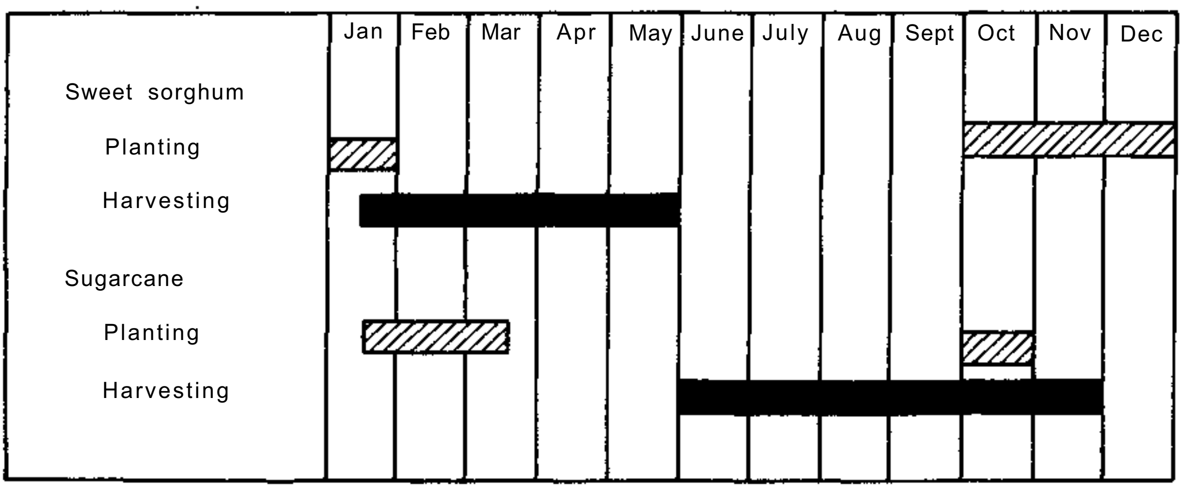


Figure 1. Planting and harvesting periods for sweet sorghum and sugarcane in Brazil (CNPMS/ EMBRAPA).

Table 1. United States Department of Energy Projections of annual maximum ethyl alcohol production in the U.S.

Source	1980	1990	2000
	(billions of liters)		
Corn	87	3.4	-
Grains, total	14.8	10.6	8.7
Sugarcane	-	2.6	2.6
Sweet sorghum	-	11.4	31.4

Source: U.S. Department of Energy (1979).

Table 2. Alcohol yield of selected crops in the United States and Brazil in 1977.

Crop	Crop yield per hectare (tonnes)	Alcohol yield per hectare (liters)
Sugarcane (Brazil)	54.2	3630
Sweet sorghum (U.S.)	46.5	3554
Corn (U.S.)	5.7	2200
Cassava (Brazil)	11.9	2137
Grain sorghum (U.S.)	3.5	1362
Wheat (U.S.)	2.1	773

Source: Brown (1980).

In January 1980, the federal government announced major new ethanol goals for both 1981 and the mid-eighties. Production of ethanol was to be increased to 1.89 billion liters for fuel in 1981 and 7.57 billion liters by the mid-eighties. Since corn is the primary distillery feedstock in the U.S., this latter goal would expend more than 20 million metric tons of corn.

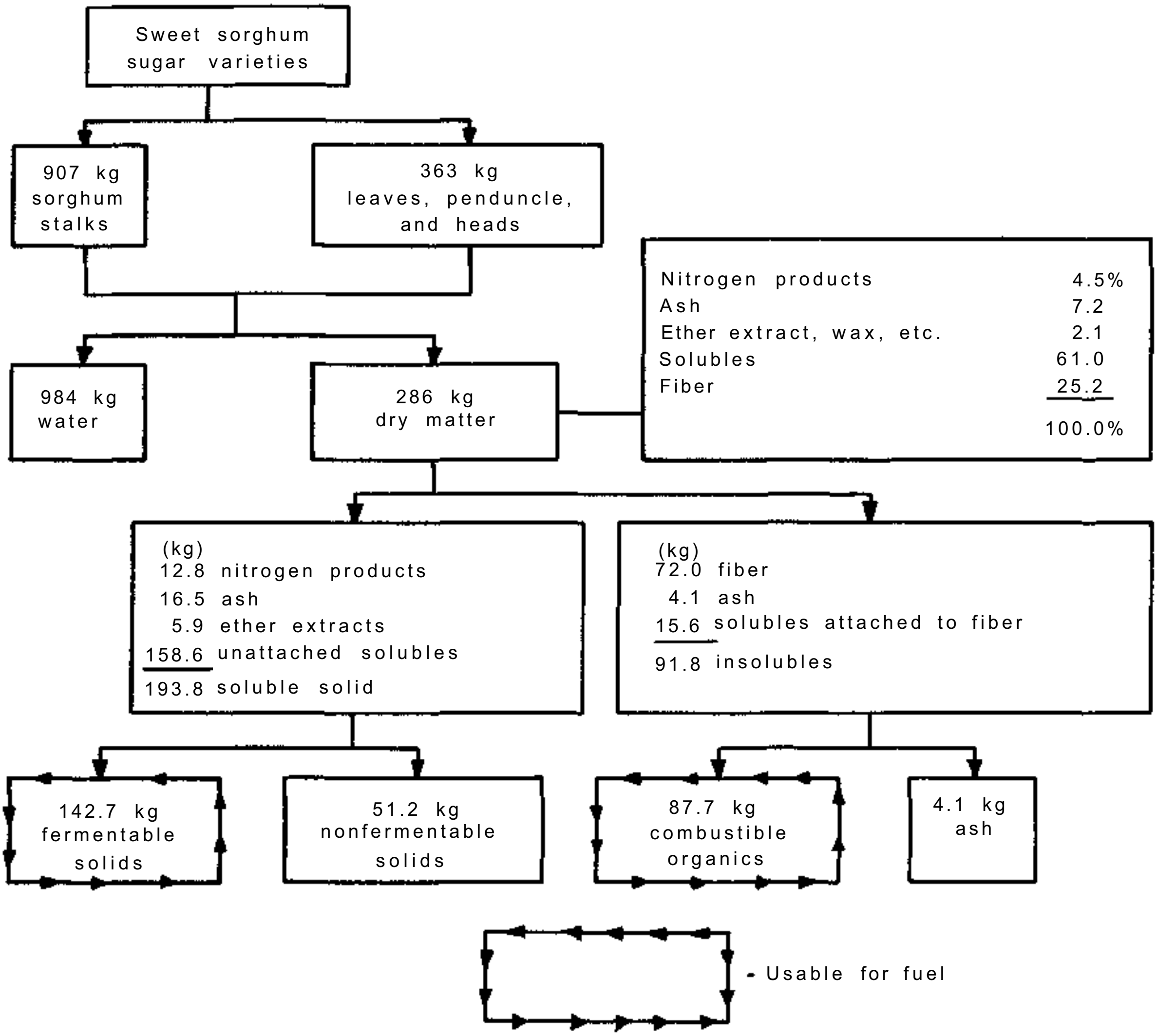
The U.S. Department of Energy (1979) is considering a major shift from corn to sweet sorghum to produce ethanol (Table 1). For the long-term forecast, it is believed that sweet sorghum could become the dominant energy crop in the United States. A total of 5.67 million hectares of cropland could be planted to sweet sorghum, which would yield 31.4 billion liters of ethanol per year. This cropland would be primarily in the Midwestern and the Southeastern United States.

Many other countries are developing national alcohol fuel programs to reduce their balance-of-payment deficits. Table 2 shows the crop and ethanol yields of selected crops. New Zealand plans to use sugar of fodder beets as the primary distillery feedstock, while Australia and Austria would use wheat. South Africa and the Philippines are planning to use both cassava and sugarcane as raw materials for the production of alcohol. Kenya and Sudan are building alcohol distilleries that will use the molasses by-product of their sugar mills. Thailand plans a flexible agricultural fuel industry that could be adapted to whatever crop might be in greatest surplus. These are but a few of the countries involved in alcohol fuel programs. The future is bright for a crop, such as sorghum, that will produce reasonable yields of alcohol per hectare on marginal lands with minimum production costs. For the present, most countries will use surplus crops or divert some current crop production to alcohol fuel programs. Future programs will bring idle or new marginal lands into the production of sugar crops.

Sweet Sorghum—A Renewable Bioenergy Resource

Types and Composition of Sweet Sorghum

Sweet sorghum grows in a wide geographical range. It can be considered the sugarcane of the temperate zone and it also has a production capacity equal or superior to sugarcane in the tropics when considered on a monthly basis. Two types of sweet sorghum have been developed by breeders: syrup varieties which contain enough invert sugars in the juice to prevent crystallization, and sugar varieties which contain mostly sucrose and very little invert sugars in the juice for crystallization. Estimated approximate compositions of sweet sorghums grown in the United States are shown in Figures 2 and 3 for sugar and syrup varieties, respectively. Sugar varieties have 50% fermentable solids and 30% combustible organics while syrup varieties, on the other hand, have 43% fermentable solids and 33% combustible organics. Total biomass yield of syrup varieties is about 30% more than that of sugar varieties; however, the total soluble solids content of sugar varieties is greater. This difference in production and composition may be due to the narrow genetic base of varieties evaluated, as the number of sugar varieties available is much fewer than the number of syrup varieties. Both types of sweet



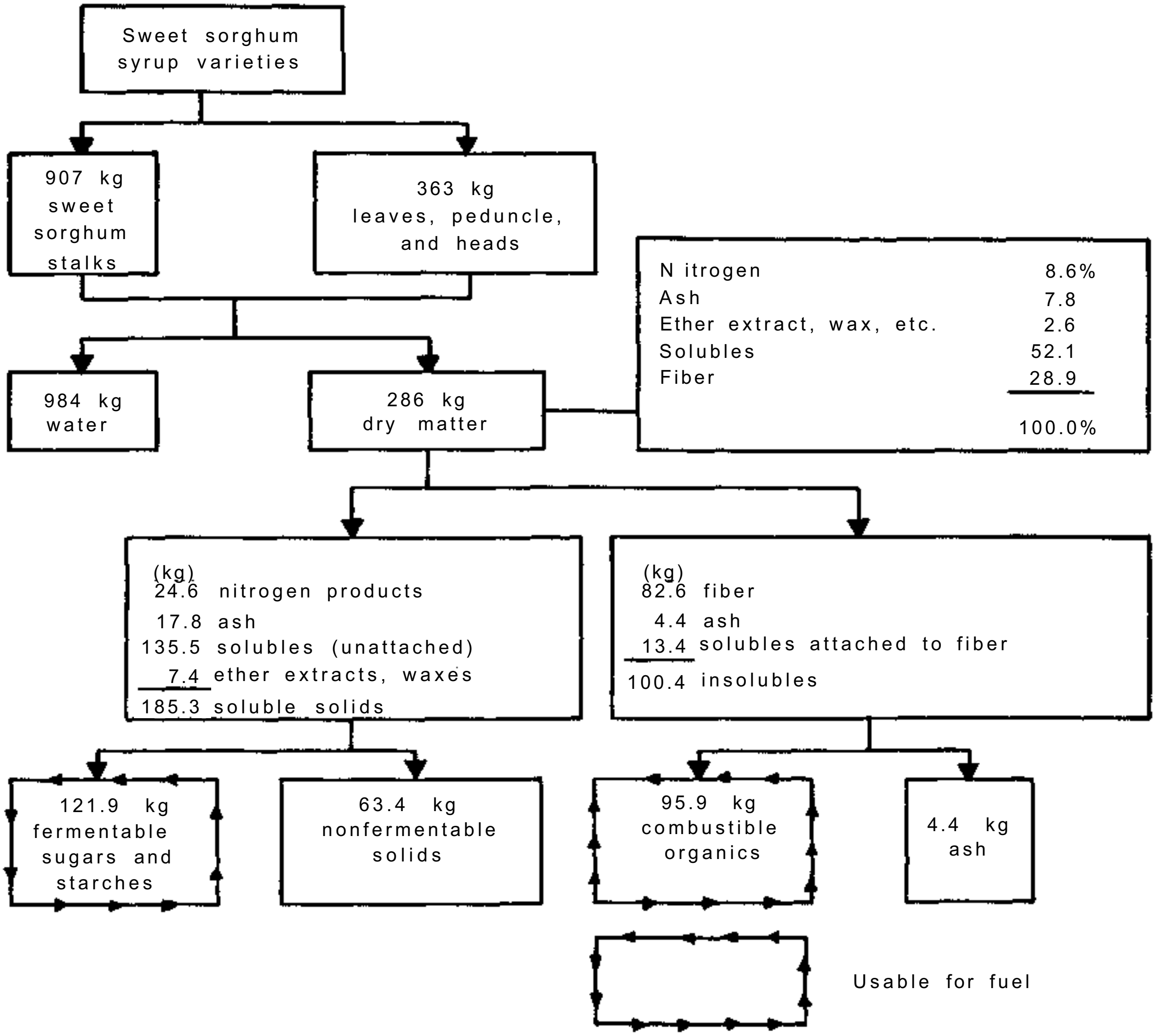
Average yields:	Tonnes/ha
Stalks	32.9
Leaves, peduncle, and heads	13.6
Total	46.5

Figure 2. Estimated approximate composition of sweet sorghum sugar varieties in the United States (Nathan 1978).

sorghum are equally suitable for alcohol production as both sucrose and invert sugars are directly fermentable.

Advantages of Sorghum Biomass

Sweet sorghum holds a great potential as a field crop for ethanol production throughout the world because it is adaptable to a wide range of growing conditions, unlike sugarcane which can only be grown in tropical and subtropical climates. Sweet sorghum also has a potential for low unit costs because it requires less water and fertilizer than does sugarcane. More energy will be recovered in the ethanol produced than is used to grow and process the crop, that is, it has a net energy ratio



Average yields:	Tonnes/ha
Stalks	47.4
Leaves, peduncle, and heads	19.3
Total	66.7

Figure 3. Estimated approximate composition of sweet sorghum syrup varieties in the United States (Nathan 1978).

that exceeds 1.0 (Sheehan et al. 1978).

The desirable characteristics of sweet sorghum varieties for ethanol production are: (1) production of a high biomass yield; (2) high percentage of fermentable sugars along with combustible organics; (3) comparatively short growth period; (4) tolerance to drought stress; (5) relatively low fertilizer requirements; (6) production of grain for food or feed use; and (7) the possibility of complete mechanization.

Sorghum—A C_4 Pathway Plant

Sweet sorghum is classified as a C_4 malate-former

Table 3. Maximum dry matter production and maximum growth rates of several crops.

Crop	Dry matter production (t/ha)	Maturity (days)	Average growth rate (gm/m^2 per day)	Maximum growth rate (gm/m^2 per day)
Napier.	106	365	26	—
Sugarcane	70	365	18	38
Sugarbeet	47	300	14	31
Forage sorghum	30	120	22	—
Forage sorghum	43	210	19	—
Sudangrass	33	160	18	51
Alfafa	36	250	13	23
Bermudagrass	35	230	14	20
Alga	44-74	300	15-22	28

Source: Loomis and Williams (1963)

which, along with sugarcane and corn, is known to have the highest rate of photosynthesis among crop plants. The C_4 pathway of CO_2 fixation is an auxiliary channel of the primary Calvin-Benson pathway (Hatch 1976). Under natural conditions, C_4 plants are not light-saturated, have CO_2 compensation points near zero, lack detectable photorespiration, and have an optimum temperature of 30-35°C.

One of the most important features of C_4 plants is their specialized leaf anatomy (Krantz-type) which provides the spatial compartmentalization required to absorb and fix low concentrations of atmospheric CO_2 in two separate sets of reactions. Atmospheric CO_2 is fixed by the C_4 pathway only in the leaf mesophyll cells while the Calvin-Benson cycle fixes CO_2 predominantly in the leaf bundle sheath cells. The net effect in C_4 plants is that they exhibit a very high photosynthetic capacity which is about twice as great as that of C_3 plants. Any CO_2 produced by photorespiration must diffuse out through bundle sheath cells and then through the actively fixing, but nonphotorespiring, mesophyll tissue before it could escape into the atmosphere and be detected by existing methods of measuring photorespiration. This of course leads to greater efficiency in utilizing CO_2.

Photosynthetic Efficiency

The data of Loomis and Williams (1963) in Table 3 show that sorghum has one of the highest dry matter accumulation rates when considered on a daily basis. In terms of average growth rate, sorghum is exceeded only by napier grass. In the data presented by Heichel (1976), sorghum had the highest food energy per unit cultural energy ratio, exceeding corn silage, sugarcane and corn grain. Considering these results, sorghum appears to be one of the most photosynthetic efficient genera that can be produced in both temperate and tropical environments, completely mechanized, and utilized on a large scale with existing technology for energy production. Undoubtedly, as more attention is placed on bioenergy production in the future, more attention will also be given to sorghum.

Technology and Infrastructure for Producing Ethanol from Sorghum

Ethanol from sweet sorghum has been produced in pilot runs in several large-scale commercial sugarcane distilleries of 120 000 liters per day or larger capacity, and is currently being produced commercially in several microdistilleries of 2000 -5000 liters per day capacity, in Brazil. In both cases the flow diagram is similar, and two processes for microdistilleries will be considered here. The differences between microdistilleries and distilleries of large-scale capacity are: the number of units of roller mills, the efficiency of extracting sugars, and the efficiency of fermentation and distillation.

In Brazil, the normal harvesting period for sugarcane is from June to November and the harvesting period for sweet sorghum is from February to May with plantings beginning in

October and November (Fig 1) In this case, the two crops supplement one another and when used together increase the period of industrial operation, decrease the unit cost of alcohol production, and increase the total amount of alcohol that can be produced by a distillery in one year The same equipment is used to process both sugarcane stalks and sweet sorghum stalks Consequently, little interest is given to the superior productivity of sugarcane or sweet sorghum but rather an economic production of both sugarcane and sweet sorghum

Sugar Extraction Using Boiler Mills

A simple flow diagram of a microdistillery using roller mills for sugar extraction is shown in Figure 4 The stalks of either sweet sorghum or sugarcane are crushed in the roller mills and the sugars extracted with the juice The efficiency of juice and sugar extraction depends upon the pressure of the *rollers* and the number of units When two or more units are used, the efficiency can be improved by using a small amount of hot water for imbibition. The efficiency also depends upon the nature of the stalk and this will be discussed in the section on plant breeding and improvement. The untreated juice is mixed with yeast and minerals, and is fermented. After the sugars have been transformed to alcohol, the beer is distilled to 92% ethanol for direct use in motors or to 100% ethanol to mix with gasoline. The bagasse can be burned in the boiler to produce steam or can be used for feed, fiber, or as a cellulose feedstock for other processes. The stillage can be used as a biofertilizer and returned to the soil or used as a feedstock in a biodigestor to produce methane and biofertilizer.

Sugar Extraction by Diffusion

A simple flow diagram of a microdistillary using a simple horizontal diffusor for sugar extraction is shown in Figure 5. The major difference in these two processes is the use of hot water to extract the sugar from the stalks in the diffusor. A roller

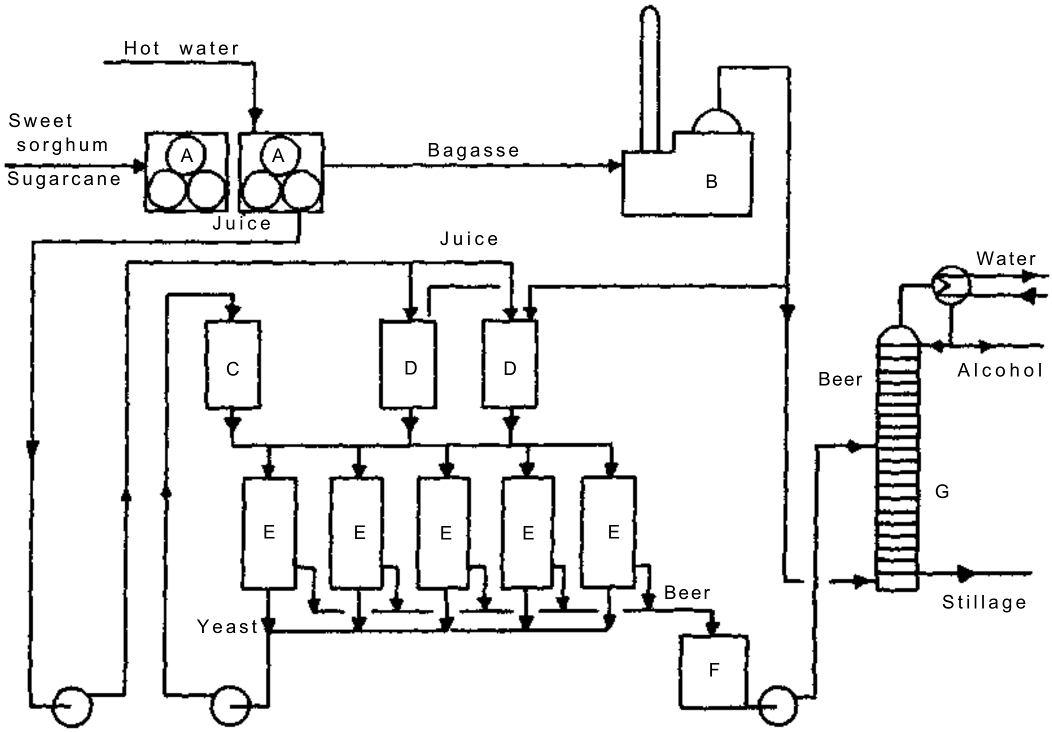


Figure 4. A simple flow diagram of a roller mill microdistillery. A—roller mill, B—boiler, C—yeast treatment and distribution tank, D—juice distribution tanks, E— fermentation tanks, F—beer-holding tank, and G—distillation column (CNPMS/EMBRAPA).

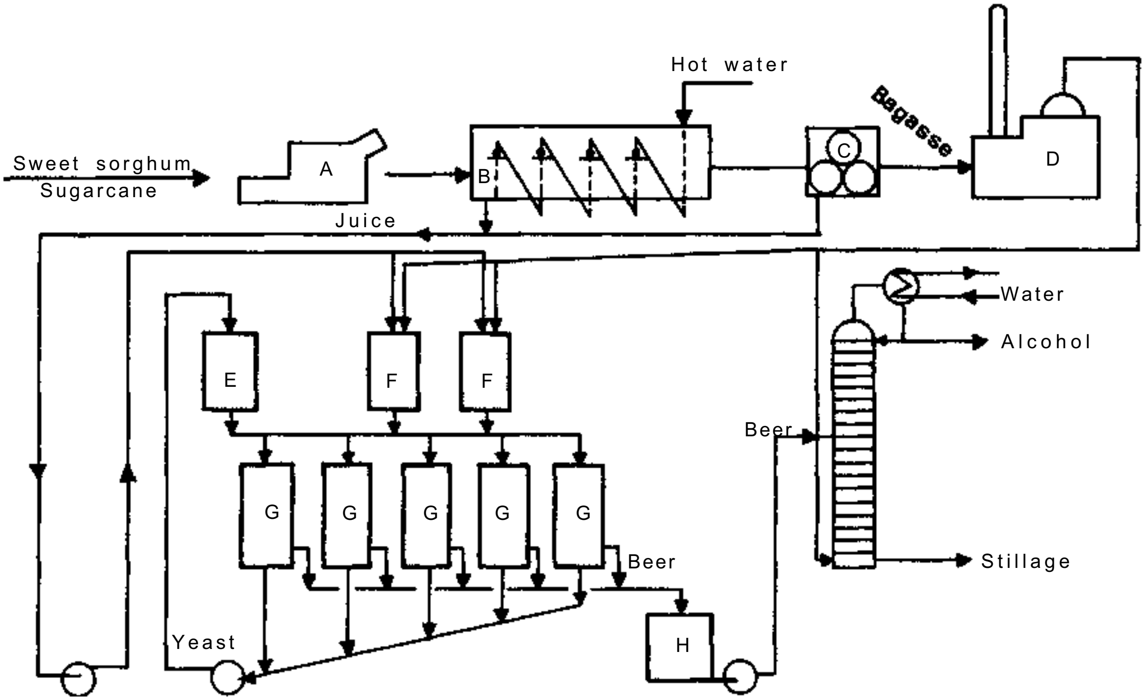


Figure 5. A simple flow diagram of a diffusion microdistillery. A—forage chopper, B—diffusor, C—roller mill, D—boiler, E—yeast treatment and distribution tanks, F—juice distribution tanks, G—fermentation tanks, H—beer-holding tanks, and I—distillation column (CNPMS/ EMBRAPA).

mill is still necessary for removing the residual juice from the bagasse. An additional roller mill may also be placed before the diffusor for greater efficiency of sugar extraction. The efficiency of sugar extraction in this process is generally greater than 90% and equivalent to large-scale sugarcane distilleries.

Sweet Sorghum Productivity and Quality

Sweet sorghums or sorgos for syrup production have been produced in the USA for over 100 years whereas the technology to produce sugar (sucrose) from sweet sorghum on a commercial scale has been available for only the past 10 to 15 years. Research on alcohol production using sweet sorghum is even more recent and for the most part has been conducted during the last 5 years. Both types of sweet sorghum serve to produce alcohol but good types to produce alcohol do not need to be associated with high sucrose purity of the sugar types or the quantity and quality of syrup produced per ton of stalks of the syrup types. The total amount and extraction of total invert sugars (fermentable sugar) is important for alcohol production.

Sweet Sorghum Productivity

The most complete sweet sorghum productivity data are from the U.S. Sugar Crops Research Station of the USDA at Meridian, Mississippi, the Texas Agricultural Experiment Station at Weslaco, Texas and the National Corn and Sorghum Research Center at Sete Lagoas, Minas Gerais, Brazil. According to Reeves (1976), Reeves et al. (1978), Reeves and Smith (1979), Broadhead et al. (1974), Coleman and Broadhead (1968), and Schaffert and Borgonovi (1980), average total yields of commercial varieties over locations and years normally range from 45 to 60 t/ha and 35 to 48 t/ha for stripped stalks. According to Schaffert and Borgonovi (1980a) and Reeves and Smith (1979) experimental breeding lines and progenies have been more productive, with yields ranging from 80 to 100 t/ha of sorghum (total plant).

Table 4. Comparison of juice quality between sweet sorghum and sugarcane in Brazil.

Trait	Sweet sorghum		Sugarcane (Sao Paulo State averages)
	Literature	National trials	
Juice extraction (%)	360-600	500-700	600-800
Retractometer Brix	16-20	14-20	18-21
Sucrose (% juice)	10-15	8-16	15-18
Invert sugars (% juice)	1-4	0,7-7.3	0,2-1,5
Total invert sugars (% juice)	14-20	14-18	16-19

Source: Schaffert and Borgonovi (1980b).

These yields have been with maturity types ranging between 110 and 140 days. Reeves and Smith (1979) have reported yields surpassing 100 t/ha fresh weight with longer maturity types. Under optimum large-scale field operations, Schaffert and Borgonovi (1980b) have reported total fresh weight yields exceeding 80 t/ha with 130 to 140 day maturity types. Grain yields normally range between 1.5 and 5.5 t/ha with average yields between 2 and 3 t/ha.

Sweet Sorghum Quality

Alcohol from sweet sorghum is currently produced with technology and equipment used to process sugarcane and during the next few years will probably continue to be processed this way. Alcohol or liquid fuel production from biomass in the future may include technology to utilize the cellulose fraction directly in the process. The discussion here will be primarily limited to the parameters dealing with ethanol production using sugarcane technology. In Table 4. sweet sorghum and sugarcane juice quality are compared. The quality of juice from sorghum is slightly inferior to juice from sugarcane, but then sugarcane has had the advantage of a substantially longer period of research than sorghum.

Schaffert and Borgonovi (1980b) have obtained average values of juice extraction (Table 5) using a hydraulic press (250 kg/cm^2 for 60 sec) ranging from 45 to 76% in a collection of 55 varieties originating from the germplasm collection at Meridian, Mississippi. Percent fiber in the same material ranged from 10 to 27%. The values of Brix and total invert sugars were relatively low as the material was sampled within a short span of time and at different stages of maturity. The variety Wray appears to be one of the most promising varieties for both commercial use and in a breeding program. Figures 6-9 demonstrate the interrelationship between the curves of refractometry Brix of the juice, total invert sugars in the juice extraction, fiber, and total invert sugar extraction for the varieties Wray, Rio, Brandes, and CMSTx 623, respectively. In Figures 10-13 the differences between these four cultivars, grown in Brazil, for refractometry Brix, total invert sugars in the juice, juice extraction, fiber, and total invert sugar extraction are shown. In Figure 13, the period for industrial utilization (PIU) for Wray is much superior to Rio and slightly superior to Brandes and CMSTx623. PIU is the period of time that total invert sugar extraction of a cultivar is the greatest and at an economical level. Wray generally has an acceptable PIU exceeding 40 days, whereas Rio generally has an acceptable period of less than 20 days. This difference is not due to the quantity of total invert sugars in the juice, but rather to differences in juice extraction and percent fiber (Fig. 12). Wray is a superior variety for both the stalk crushing and the diffusor process of sugar extraction. The varieties Brandes and CMSTx 623 also have values more desirable than Rio. Reeves and Smith (1979) have obtained between 2 and 4% starch in dry stalks of sorghum. Smith (personal communication, USDA, Texas Agriculture Experiment Station, Wes/aco, Texas, 1978) has reported similar values of starch in the juice extracted from stalks. This starch does not interfere in the fermentation and distillation process but could be hydrolized and converted to simple sugars before fermentation. Figure 14 demonstrates the major potential uses of sweet sorghum for food, fiber, fertilizer, ethanol and methane gas production. The only phase untested

Table 5. Average values of Brix, total invert sugars, juice extraction, and fiber of selected sweet sorghum varieties grown at Araras, Sao Paulo, Brazil in 1981.

Variety	Brix	Total invert sugars (% juice)	Extraction (% sorghum stalk)	Fiber (% sorghum stalk)
Brandes	16.7	14.7	63.2	12.5
Honey	13.0	11.1	73.0	11.6
Sart	14.7	12.4	69.8	14.8
Rio	16.4	14.2	57.6	16.1
MN 1500	14.2	11.4	61.1	185
MN 1048	14.1	134	56.5	22.0
MN 1030	15.2	10.0	476	25.8
MN 4008	10.6	10.5	74.9	12.0
Williams	13.5	12.4	70.5	10.1
MN 4080	14.1	—	45.7	26.6
Wray	19.3	16.8	67.5	14.8
Theis	16.4	14.2	71.5	14.8
Redlan	10.5	7.4	67.0	13.6
Tx623	10.8	7.0	64.0	13.6

Source: Schaffert and Borgonovi (1980b).

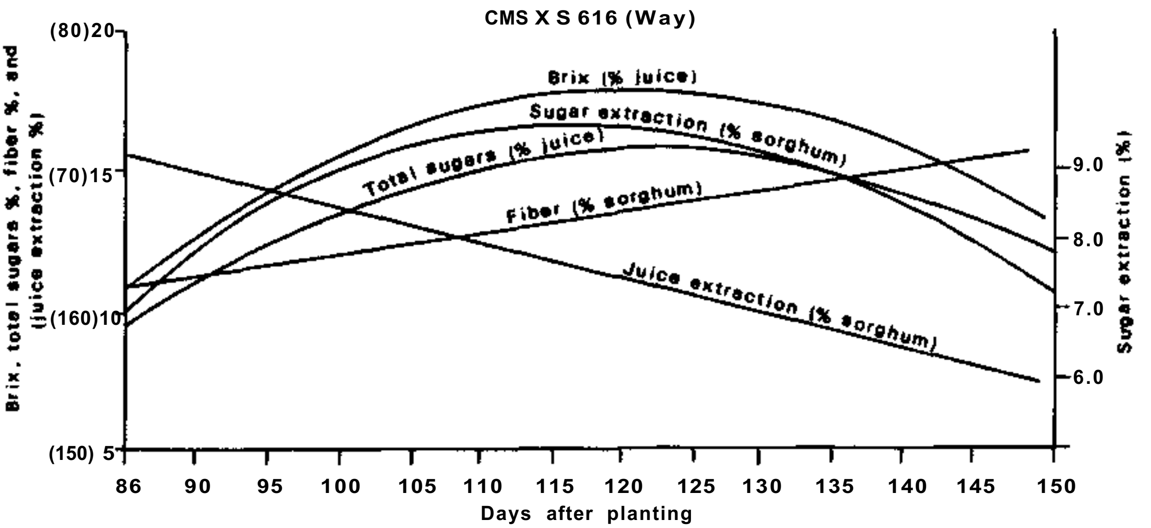


Figure 6. The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of sorghum stalks during the maturity phase for the variety Wray grown in Brazil (CNPMS/EMBRAPA).

at the National Corn and Sorghum Research Center in Brazil is the hydrolysis of the bagasse. In the case where this system is integrated with a greenhouse system, the CO_2 from the fermentation could be used to increase the CO_2 concentration in the greenhouse. The biofertilizer can also be used in a greenhouse system. Figure 15 demonstrates an integrated rural energy system developed at the National Corn and Sorghum Research Center in Brazil that can operate on a

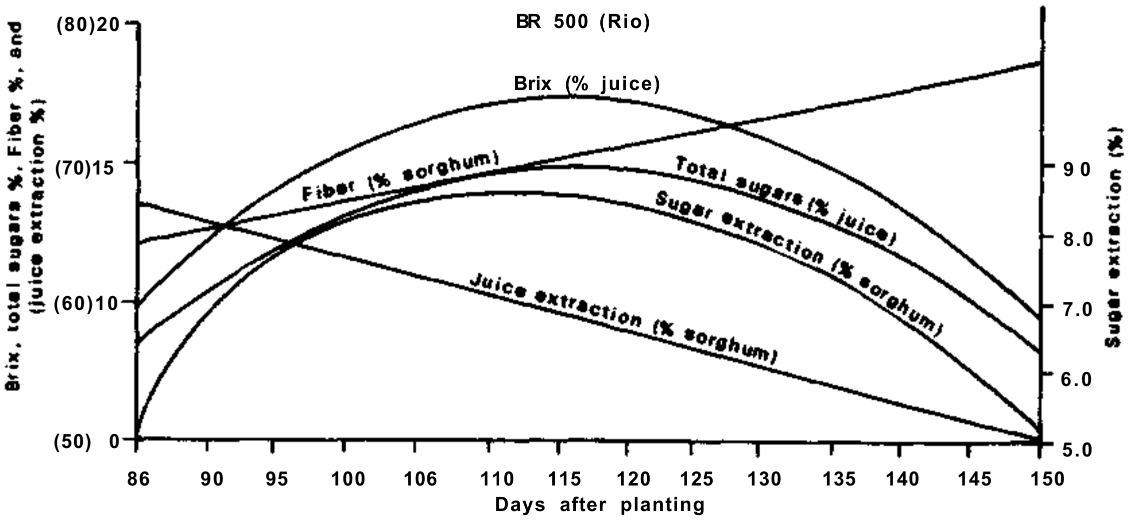


Figure 7. The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of sorghum stalks during the maturity phase for the variety Rio grown in Brazil (CNPMS/EMBRAPA).

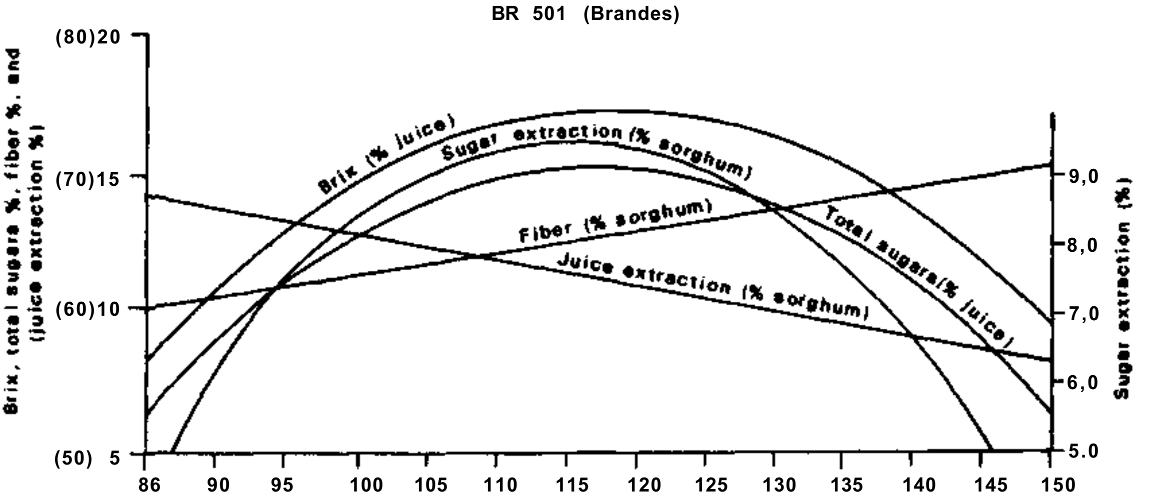


Figure 8. The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of sorghum stalks during the maturity phase for the variety Brandes grown in Brazil (CNPMS/EMBRAPA).

zero petroleum and electrical energy input basis. Many other options are also possible for total utilization of the sorghum plant.

Economics of Producing Alcohol from Sorghum

Table 6 shows the range and average yields of sweet sorghum and ethanol production used for planning purposes in Brazil. Agricultural yields can be much higher than 37.7 metric tons of stalks and 2.2 metric tons of grain per hectare under good management. The average industrial yields are those obtained by large industrial operations and are currently about 20% less for microdistilleries. Utilizing both the grain and the stalks to produce alcohol, one hectare will produce 3387 liters of ethanol in 4 months. The utilization of one

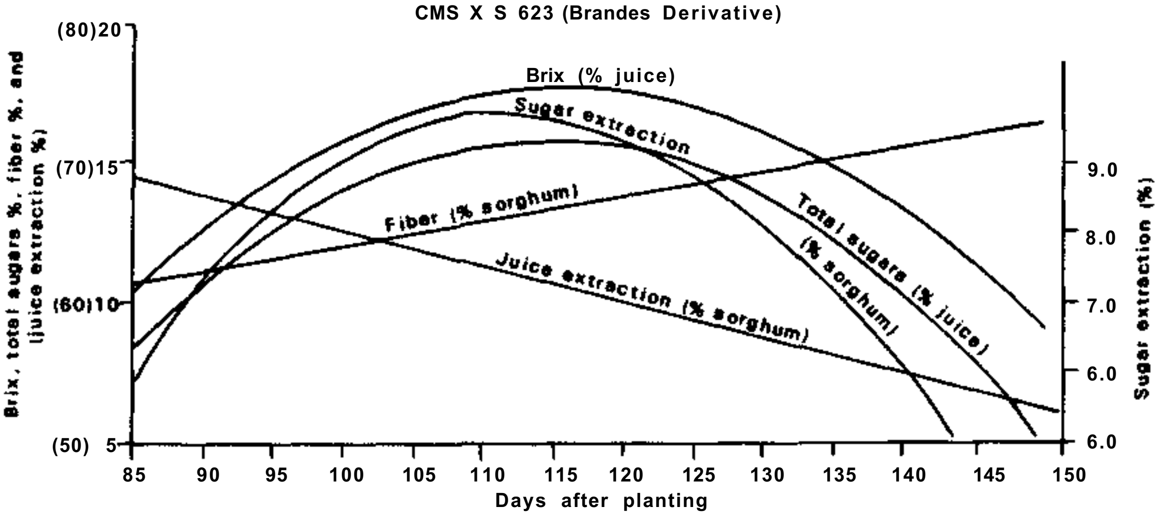


Figure 9. The interaction of refractometry Brix and percent total invert sugars in the juice and percent fiber, percent juice extraction, and percent sugar extraction of sorghum stalks during the maturity phase for the variety CMSXS 623 grown in Brazil (CNPMS/EMBRAPA).

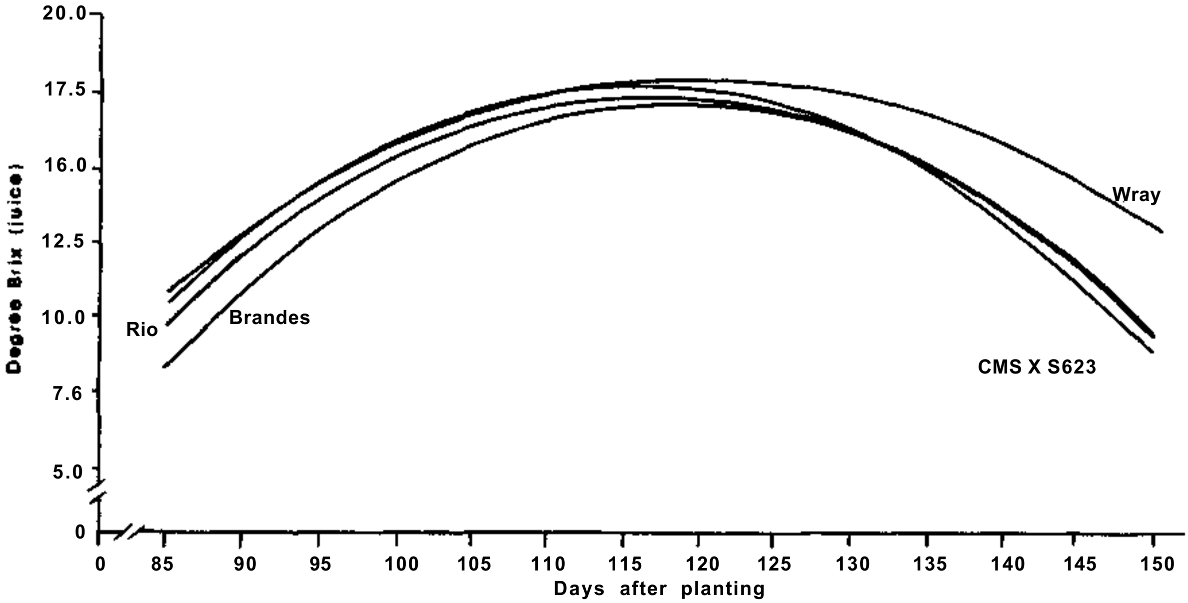


Figure 10. The differences between four cultivars grown in Brazil for refractometry Brix of the juice during the maturity phase of production (CNPMS/EMBRAPA).

ratoon crop would increase this value by 50 -80%. Table 7 shows the production costs of ethanol from sweet sorghum stalks in Brazil in November of 1980 considering two levels of stalk production and three industrial production levels representing three types of microdistilleries, one crushing unit, two crushing units and a diffusion unit respectively. Horizontal and vertical diffusion units for microdistilleries are currently being evaluated in Brazil.

Table 6. Agricultural and Industrial yields of sweet sorghum in Brazil.

Component		Agricultural yield (t/ha)	Alcohol yield	
			(liter/t)	(liter/ha per harvest)
Stalks	Range	22-66	55-85	1210-5610
	Average	37.7	70	2639
Grain	Range	1.4-6.6	310-370	434-2442
	Average	2.2	340	748
Total	Range			1644-8052
	Average			3387

Source: Schaffert and Borgonovi (1980b).

Table 7. Production costs of alcohol from sweet sorghum in Brazil in microdistilleries, November 1980.

Item	US$
Production costs/ha	320
Cost/t stalks (30 t/ha)	10.67
Cost/t stalks (40 t/ha)	8.00
Cost/l alcohol (45 liter/t and 40 t/ha)	0.22
Cost/l alcohol (59 liter/t and 40 t/ha)	0.20
Cost/l alcohol (68 liter/t and 40 t/ha)	0.17

Source: CNPMS/EMBRAPA. Caixa Postal, 151. 35700-Sete lagoas, MG, Brazil.

Future Sorghum Biomass Research and Development

Development of Improved Cultivars

Insensitivity to Photoperiodism

One of the factors limiting sorghum biomass production in the tropics and subtropics is the sensitivity of most of the cultivars to photoperiodism. This seriously limits varietal management for a prolonged harvest period of several months. Two principal sources for insensitivity used in the Brazilian sweet sorghum improvement program

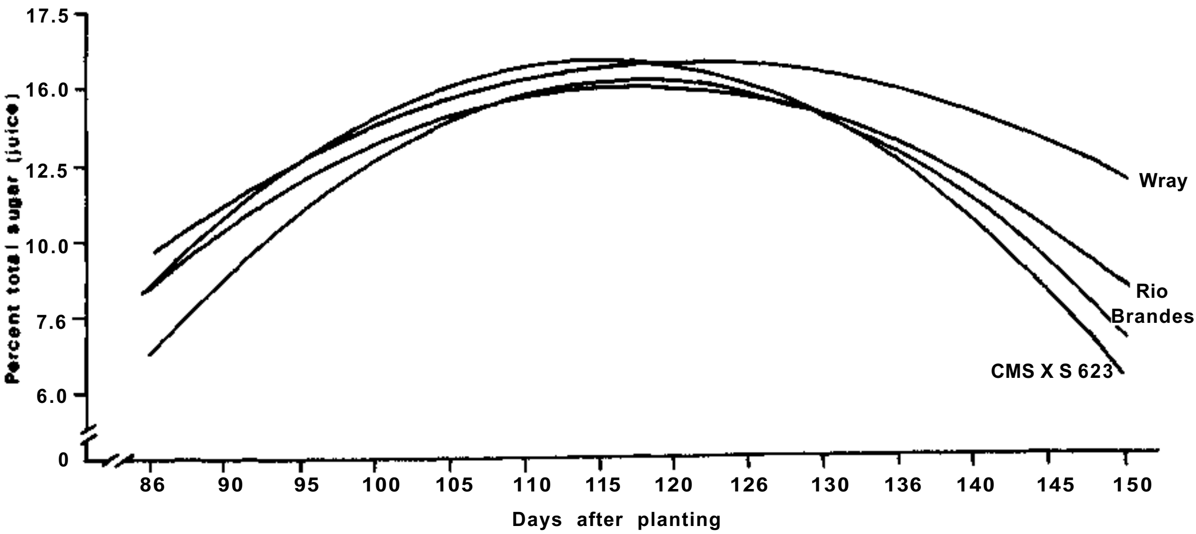


Figure 11. The differences between four cultivars grown in Brazil for total invert sugars of the juice during the maturity phase of production (CNPMS/EMBRAPA).

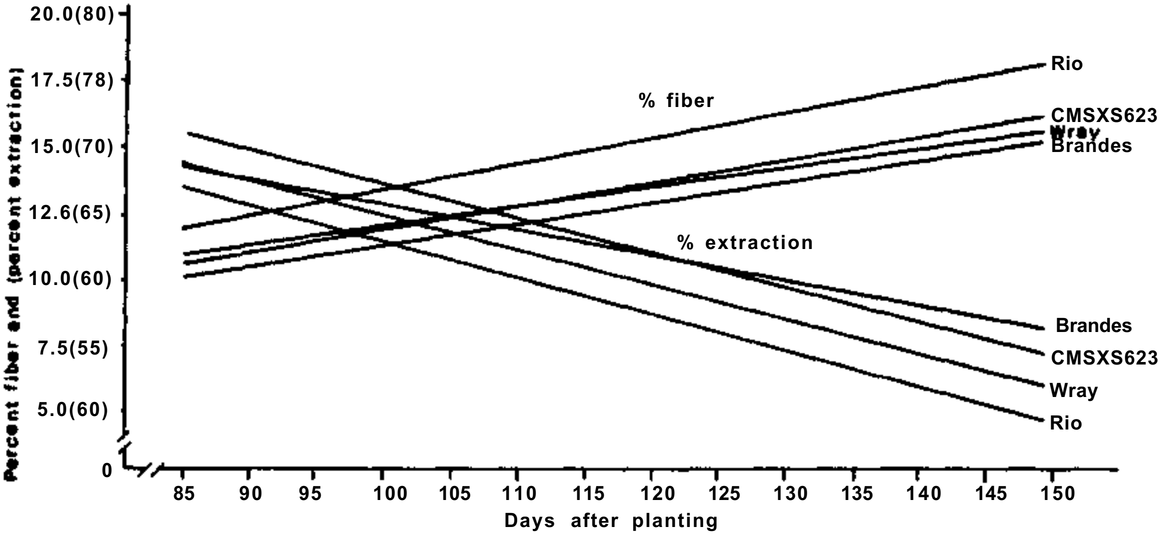


Figure 12. The differences between four cultivars grown in Brazil for juice extraction and fiber of the stalks during the maturity phase of production (CNPMS/EMBRAPA).

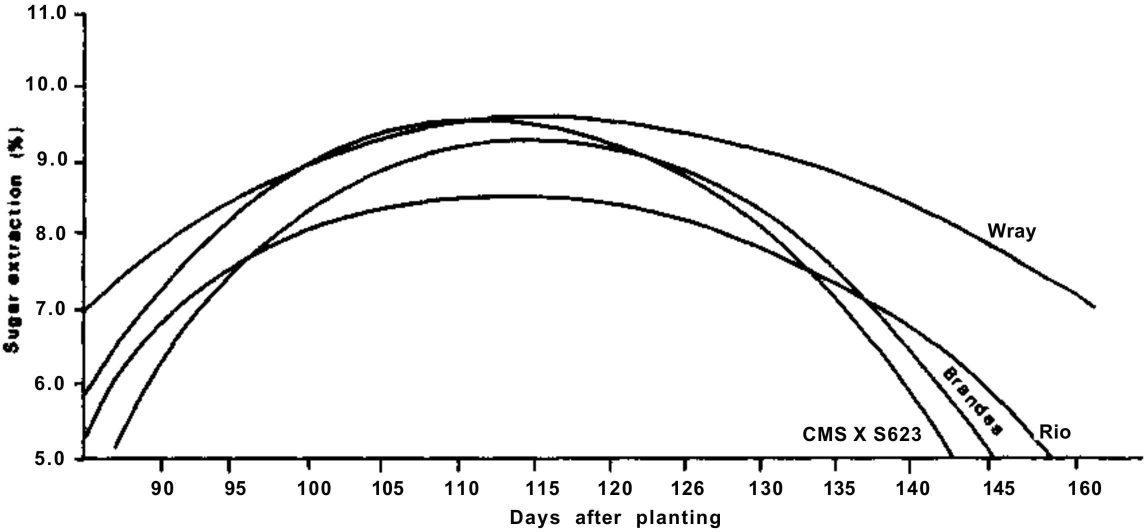


Figure 13. The differences between four cultivars grown in Brazil for total invert sugar extraction of the stalks during the maturity phase of production (CNPMS/EMBRAPA).

are the varieties Wray and Honey. The varieties Brandes, Theis, Dale, Roma, and Ramada are all very sensitive and the variety Rio is intermediate in reaction.

Disease and Insect Resistance

Cultivars with good levels of resistance to foliar diseases are needed to maintain a high percentage of green leaves until harvest to improve the biological value of the bagasse for animal feed. The varieties Brandes and Wray have adequate levels of disease resistance in Brazilian conditions but are susceptible to *Cercospora sorghi.* Resistance or immunity to the sugarcane mosaic viruses is necessary for cropping adjacent to sugarcane. Good insect resistance is also necessary, especially resistance to the sugarcane borer (*Diatraea* spp).

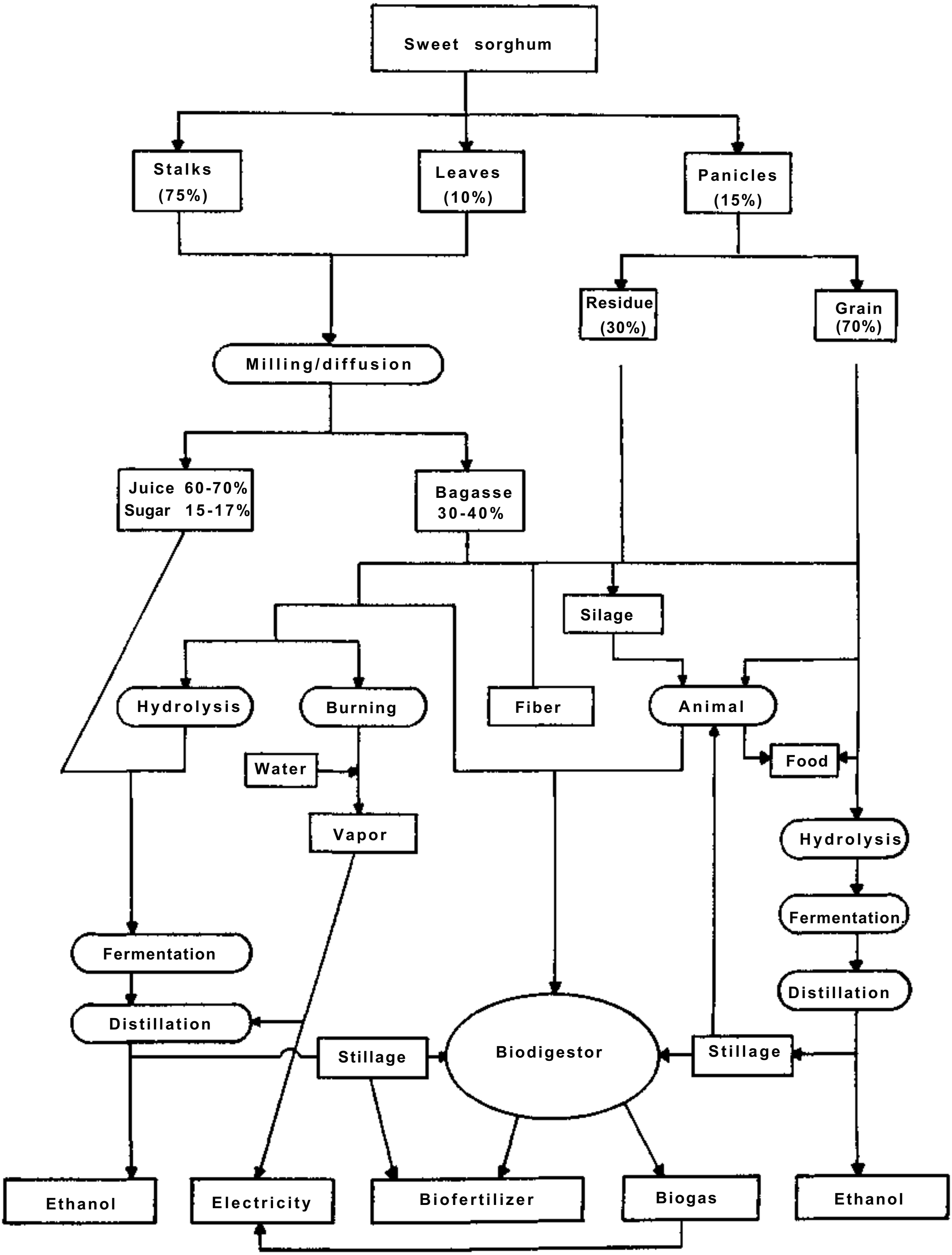


Figure 14. The potential uses of sweet sorghum for food, fiber, fertilizer, ethanol, and methane gas production (CNPMS/EMBRAPA).

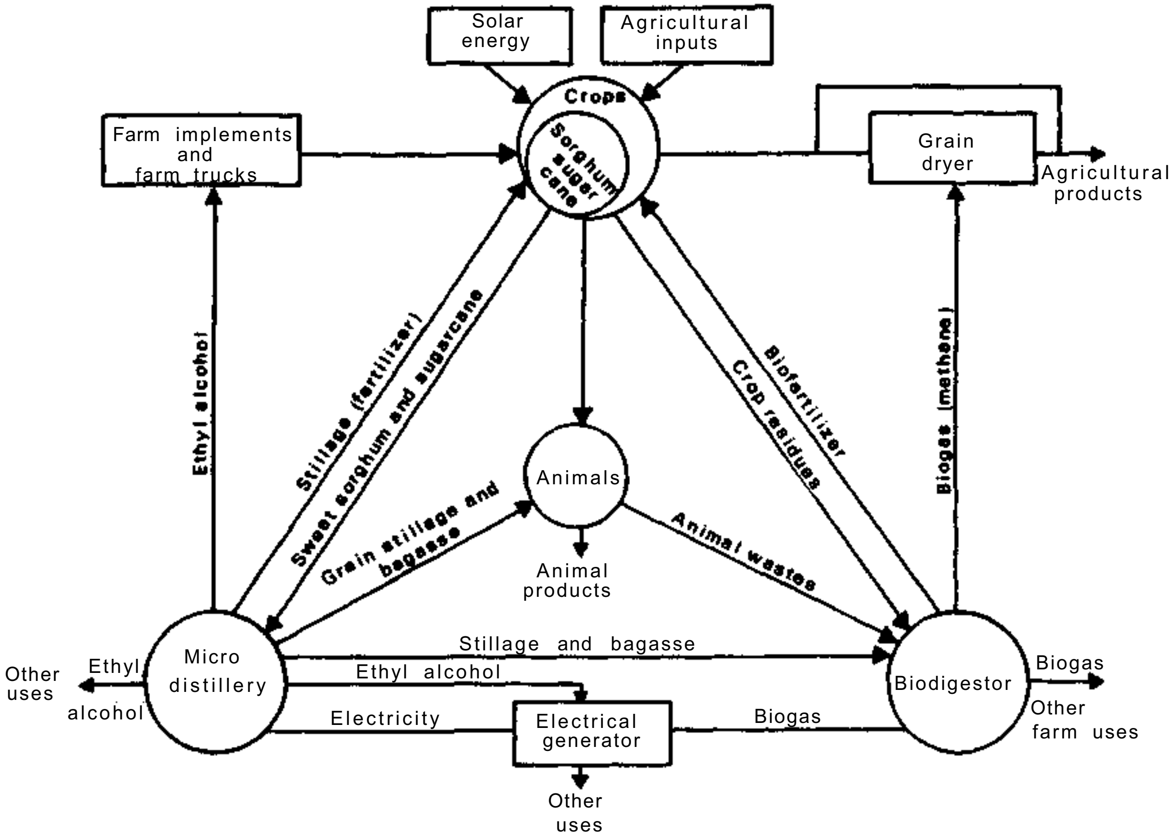


Figure 15. An integrated rural energy system developed at the National Corn and Sorghum Research Center of EMBRAPA in Brazil (CNPMS/EMBRAPA).

Male-sterile Sweet Sorghum Lines

A new series of A and B sweet sorghum lines is needed to produce hybrids. Hybrids produced with the available A-lines are significantly more productive but the juice quality is reduced and the level of total invert sugars is more variable than for commercial cultivars. Lines such as Redlan, Tx 622, Tx 623 and Tx 624 have not produced adequate hybrids. The cost of hybrid seed production is much less than the cost of variety seed production due to harvest costs.

Maturity Groups

New cultivars with varying maturity lengths, 100-210 days, are needed to improve varietal management for a longer total harvest period. Most cultivars produced in the tropics normally reach maturity between 110 and 140 days.

Improved Industrial Quality

Cultivars with greater total sugars, lower fiber, and greater sugar extraction, as well as cultivars with a longer PIU are needed.

High Energy Sorghum

High energy sorghums, as proposed by Miller and Creelman (1980), with high potential levels of grain production and large quantities of fermentable sugars in their stalks should be developed. This will provide a greater range of processing systems that can be employed for food, feed, and energy production.

Stress Tolerance

It is necessary to develop sorghums for biomass production that are more tolerant to moisture stress, toxic aluminum stress, and acid soil stress so that these can be grown in the marginal lands that are acid, with toxic levels of aluminum, and are subject to moisture stress. In Brazil alone there are more than 180 million hectares of land with these characteristics that are not currently in crop production.

Development of Basic Studies

Seedling and Initial Growth Rates

Sweet sorghums are slow starters, they have slower growth rates than grain sorghum for the first 20-30 days of growth. The factors associated with this trait need to be identified to allow breeders to develop fast starters.

Herbicide and Insecticide Resistance

Sweet sorghums are generally much more susceptible to chemical damage than other sorghums and grasses. Sources of resistance need to be identified for utilization in a breeding program. The use of protection agents mixed with the seed to give a greater range of herbicide use is also needed.

Growth Curves

The development of growth curves associated with sugar metabolism and accumulation is needed as well as studies to determine the optimum stalk size for maximum sugar production and maximum sugar extraction during the industrial processing phase. Other biochemical and physiological aspects of sugar production and accumulation also need to be studied.

Development of Improved Management Practices

Row Spacing and Plant Density

Optimum plant spacing and density studies need to be developed to determine the correct combination of total productivity, stalk size, and the the type of industrial processing. Stalk size and number are also important factors in manual harvesting efficiency.

Date of Planting Studies

Regional date of planting trials for adapted cultivars are necessary for optimum varietal management.

Mechanization

The lack of adequate planting equipment necessary for uniform stands is a limiting factor in many of the tropical areas of the world and adequate planting and management systems need to be developed. Systems of mechanized harvest or semimechanized harvest compatible with the industrial process need to be developed.

Weed Control

Adequate weed control systems need to be developed. The use of seed protection agents for greater herbicide choice and combinations of mechanical and chemical control methods need to be developed and improved.

Ratooning

Production systems utilizing one or two ratoon harvests need to be developed. Until recently, with the introduction of photoinsensitive varieties ratoon cropping was not possible in the short-day tropical environments. Schaffert and Borgonovi (1980a) obtained total production of 166 t/ha sorghum in three harvests near Petrolina, Pernambuco, Brazil with a selection from the variety Honey in one year. New cultivars and systems for ratoon cropping are essential for efficient varietial management.

Fertilizer Calibrations

Fertilizer recommendations need to be developed for high yielding sweet sorghums where the entire crop is removed and stillage and biofertilizer may or may not be applied to the soil. Reeves et al. (1978) reported a range of removal of potassium from the soil varying from 132 to 515 kg/ha for three sweet sorghum cultivars. The phosphorus removed was much less and ranged from 15 to 37 kg/ha.

Development of More Efficient Industrial Processes

The most promising system for the immediate future, using sweet sorghum, is the microdistillery with a capacity ranging from 500 to 5000 liters per day. These are small cooperative or large farm systems where approximately 10% of the crop land area is needed for zero petroleum energy inputs and where the by-products can be utilized on the farm. Additional studies of stillage and biofertilizer rates need to be made for optimum utilization of these products. Improving the efficiency of sugar extraction, cellulose hydrolysis (biodigestor), fermentation, distillation and heat transfer is important. Technology for more efficient utilization of ethanol and biogas in farm motors is also desirable. The biological values of the by-products for animal feed also need to be evaluated. Economical methods to utilize the starch in the extracted juice for alcohol production need to be developed for microdistilleries.

Fuel or Food or Fuel and Food

Using energy crops as a source of fuel places a new demand on agriculture to produce an adequate food supply. In the 1980s we will see a much larger quantity of agricultural resources being diverted to the production of nonfood crops than could have been imagined in the 1970s. Food-exporting countries such as the United States, Brazil, Australia, New Zealand, and South Africa are actively pursuing programs for the conversion of crops into alcohol for fuel on a commercial scale. As oil prices increase, distillers will be able to increase the price of ethanol and will become competitive in grain markets. The use of sugar crops for liquid fuel will also compete for the world's cropland to a large extent. The use of sweet sorghum for liquid fuel production does not need to be a question of fuel or food but rather an option of fuel and food.

Conclusion

If the production of large quantities of ethanol for fuel from sugar crops becomes a reality, the future of sweet sorghums in the eighties and beyond indeed looks bright. Sorghum breeders must utilize the tremendous genetic diversity of this genus and direct breeding efforts toward developing improved varieties and hybrids as a crop for fuel and agronomists must develop production systems for the many industrial options available for processing sweet sorghum.

Acknowledgments

The authors wish to thank PLANALSUCAR (the Sugarcane Improvement Authority of Brazil) in Araras, SP for their support of sweet sorghum research and analysis of samples for the maturity curves presented in this paper, and the National Corn and Sorghum Research Center (CNPMS) of Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) for other important data used.

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Session 7 Food Quality and Utilization

P. Pushpamma* Discussant

It is a fact that the success of any cultivar at the consumer level depends on several of its characters, rather than on any single factor. It is recognized that until a decade ago, food scientists and nutritionists contributed very little to improve the postproduction system of sorghum, which includes storage, processing and utilization. When we first started the IDRC project in 1974 on dryland crops, we were surprised to note that there was hardly any information available on storage losses in sorghum, quality characters of sorghum foods, and milling quality of sorghum. For these areas of sorghum, I feel that this Symposium has shown that impressive progress has been made recently.

The first paper in this session was presented by Reichert on the present status of sorghum milling and future needs. He made an excellent review of the various efforts made in improvising and adopting rice and wheat dehullers to suit the structure of the sorghum kernels.

A number of the traditional sorghum preparations require dehulled grain which is obtained by pounding, mostly by the wet method. He pointed out the drudgery of women in day-to-day processing of sorghum, who are compelled by the poor keeping quality of the flour. This is one of the critical factors contributing to the tendency of sorghum consumers to shift to more convenient grains like wheat and rice.

Reichert especially emphasized the need for developing mechanical milling, i.e., large-scale processing units for urban markets, and also medium to small size mills for rural consumers. The latter definitely prefer to get their own grain in small batches. This applies to wheat and rice in rural areas. However, such efforts are conspicuously lacking in India, though the problem is no less in magnitude.

He also referred to the existing gaps in the knowledge on quality required for sorghum flour. One of the key issues is the shelf life of processed flour. Improving the quality depends upon the removal of the germ which contains the best quality protein. This also raises the question of removing the oil and a loss of calories.

There are other nutritional implications of processing which require careful consideration. In traditional milling the level of dehulling is adjusted to the nature of the grain. This is necessary not only to maximize the extraction rate but also to retain nutrients. This is especially important as the outer layer of the endosperm and the germ contain a higher concentration of nutrients. It may not be out of place to recall here our experience of introducing rice milling: Excess milling of rice for better acceptability increased the prevalence of vitamin B deficiency in rice consuming areas. When this fact was recognized, hand pounded rice was introduced into the market as "health food" at a higher price as the practice of hand pounding was totally replaced by rice mills. It is therefore necessary to evaluate the dehullers for their performance in terms of minimizing nutrient losses and also for adjusting the level of dehulling depending on the grain. Appropriate biological evaluation of grain before and after dehulling is necessary as apparent losses may be deceptive as in the case of high-tannin varieties. Similarly, the calcium content of any variety is reduced in milling but availability is increased.

Regarding the gaps in the quality requirement of flour, it may be different for different sorghum products. For this purpose, a study of the characteristics of the best quality and poorest quality grain for different products may be useful in fixing the maximum and minimum acceptable range of quality parameters used for flour quality.

The introduction of suitable dehullers along with flour mills will be necessary because:

- It reduces the drudgery of women in the sorghum eating areas.

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- It converts sorghum as a convenient grain.
- It improves the quality of sorghum products.
- It checks the tendency of shifting from sorghum to other grains.
- It is an essential step to develop composite flours and to commercialize sorghum products.

Progress in the areas of sorghum food quality, although not spectacular, is very impressive. Our knowledge and understanding of quality criteria of sorghum food and related grain characteristics are much better than a decade ago. Rooney and Murty not only suggested broad guidelines on the grain quality requirements for different sorghum foods but also projected the future scope of coming up with very specific food quality tests which will be done using a small sample and in large numbers useful for screening purposes.

They made a very specific comment on why it is difficult to develop food quality parameters for sorghum. Sorghum products are exclusively used for home consumption, unlike rice and wheat, the products of which are industrialized.

Sorghum food preparation is more skill oriented. While developing quality parameters it is very essential to make an extensive study of the skill oriented traditional methods of sorghum food preparation and incorporate their significant features in the standard laboratory recipes.

One of the outstanding contributions of Rooney and his team is the description of the kernel structure of sorghum and the possibility of using endosperm quality as an index of the suitability of the grain for a particular product. Sorghum breeders will be delighted to note that all types of endosperm are suitable for one or the other product: soft kernel for leavened bread; hard kernel for rice and porridges; intermediate texture for *rati* and *tortillas.* Sorghums of white or light yellow color are widely preferred and dark brown colors are unacceptable. One of the conclusions made was that except in the case of *tortillas,* the color of the product is not very critical, but our experience in India is different in this respect. One of the most evident grain characters, as well as product characters, is color.

The most complicating factor brought out in their paper is the instability of the food quality characteristics when tested across localities due to genotype x processing method interactions. There is also an indication of probable seasonal differences. Their data suggest that locational testing and seasonal testing should be part of the regional testing program.

However, one of the optimistic notes is in the variation in the quality of *td* with pH. It indicates that slight adjustments in pH may possibly produce acceptable *td* within a moderate grain quality range.

They emphasized the need for assessing the grain qualities of most acceptable and least acceptable varieties to determine the acceptable range in the desirable grain characters. This will be especially important in screening out the extremely poor and the least acceptable lines.

They also emphasized the need for developing status foods for commercial production and evolving grain varieties suitable for this purpose.

The scope and limitations of improving the nutritional quality of sorghum are described by Axtell, Ejeta and Munck in a very pragmatic way. The paper brought out a number of gaps existing in our knowledge about the nutritional quality of sorghum. Several questions were raised about the ability of sorghum to support the growth of children and also its desirability as human food.

One of the major issues discussed by them was tannin in sorghums, and the interaction between tannin content and protein quality.

In the International Symposium on Sorghum Grain Quality, Butler gave an account of tannins and made one interesting comment that because of their high affinity for prolamine, the biologically available protein in the high-tannin varieties is of better quality and probably this is nature's way to protect sorghum eaters.

Axtell. however, suggested that two alternatives for detoxicating tannins are alkali treatment and denuding. A better understanding of the biochemistry of sorghum tannins and their interaction with seed protein needs major emphasis in the eighties.

Axtell also described the present status of the high-lysine breeding program and the future prospects. The situation seems to be quite encouraging. He mentioned that in Ethiopia, the homeland of the high-protein and high-lysine varieties, the heads are roasted in the late dough stage and the grain is eaten in a mixture with normal varieties because the high lysine grains have a superior flavor.

He also discussed the problems confronting the development of suitable high-lysine varieties. The dented grain (lines with a high-lysine content) and low yield of the Ethiopian lines *are* the critical characters for the low acceptability by the farmer.

The possibility of introducing these high-lysine varieties in their present form is ruled out.

Axtell made an excellent suggestion about using these varieties for special purposes for feeding vulnerable groups, such as children on their weaning diets, and pregnant and lactating women. The possibility of using these grains in feeding programs, which are operated by governments, both in unban and rural areas has good prospects. One of the highlights of his paper was the attempts being made in chemically inducing high-lysine mutants.

Several questions were raised about the digestibility of sorghum proteins and the desirability of sorghum as a human food, especially for children. MacLean's experiment in Peru in feeding sorghum to preschool children revealed very discouraging results showing an extremely poor value of sorghum protein for human beings. His conclusion that it is totally unfit for human consumption jolted the sorghum scientists, particularly the nutritionists. On second thoughts however, it was realized that probably where sorghum is considered as a food after going through several changes in various steps involved in primary and secondary processing in traditional sorghum foods, the situation may be different. Preliminary experiments conducted with *kisra* definitely indicated a possible improvement in digestibility of sorghum, during processing. A similar improvement in the biological quality of both protein and carbohydrates in these sorghum foods definitely deserves the attention of biochemists and nutritionists.

Another aspect which needs consideration in the context of sorghum food quality is the dietary pattern of the sorghum eating population. Invariably sorghum is consumed in combination with other foods, especially legumes, and this pattern is very well reflected in the cropping pattern of sorghum growing areas. Work carried out in our institution as well as in other places demonstrated that sorghum when consumed in suitable combination with legumes is not inferior to any other cereal in its nutritional quality. However, there is not much scientific evidence documented in support of this hypothesis, except the experiences of people working in these areas. From this one can obviously draw the conclusion that sorghum foods received very little attention by nutritionists in the seventies and that they may have to work harder in the eighties to answer some of the vital issues raised here today.

Food scientists and nutritionists will be able to contribute substantially in promoting sorghum and sorghum products for human consumption by filling the gaps in our knowledge on the food quality of traditional sorghum foods. Assessment of the nutritive value of these foods separately and in combination with other complementary foods like grain legumes, and developing suitable processing technology to introduce sorghum foods into the urban markets are essential to create enough demand for surplus grain.

I am sure that we sorghum scientists will be delighted to see small processing mills operating throughout the SAT region and a variety of sorghum foods occupying a place in the market along with other cereal foods.

Session 7 Food Quality and Utilization

Discussion

Bapat

What is the maturity range in the sweet sorghums? At what stage is the crop harvested for extracting alcohol?

Schaffert

There are varietal differences and the right stage of harvest is at physiological maturity.

Riccelli

I would like to inform all those interested in sweet sorghums that in our program we have male-sterilized several of them and they are available upon request.

Clegg

The University of Nebraska is developing a demonstration farm based on renewable fuels. Sweet sorghum is the principal crop for alcohol production. We have noticed that the growth response of hybrids is rapid. We are interested in hybrids because we need to harvest before we get a killing freeze and we are also interested in grain for feed.

Schaffert

We have also worked with hybrids. We have observed that varieties have a much slower initial growth than hybrids but our hybrids do not have stable and adequately high total concentrations of invert sugars to be used.

Balasubramanian

Do you think sweet sorghum can replace sugarcane in the tropics? What is the popularity of grain obtained from sweet sorghum for food?

Schaffert

(1) Sweet sorghum cannot replace sugarcane; we are using sweet sorghum to cover the season in which sugarcane is not available.
(2)Grain quality is a variable trait and can be bred on sorghums with sweet stems.

Balasubramanian

Is there any information on the carcinogenic quality of high-tannin sorghum grains?

Axtell

Not really—only some epidemiological evidence from Tibet and China is known.

Ryan

Tannins have an adverse effect on the nutritional benefits to be derived from high-lysine sorghums. Even if we are successful in dehulling the high-tannin portions of sorghum grains with improved milling techniques, much tannin would remain from other components of the diet such as tea, tobacco, etc. If sufficient tannins remain from nonsorghum components, then the beneficial effects of improving lysine content of sorghum may be negated.

Axtell

We regard improvement for high lysine as a research problem and not as a breeding problem.

Naingaad

During fermentation to produce sorghum beer, is methanol development a problem?

Rooney

Methanol is not a problem in the production of sorghum beer. Methanol is sometimes a problem in improperly distilled, alcoholic beverage. Many studies of fermented sorghum products indicate that there is nothing to fear from methanol production during fermentation.

Miller

What is the future for development of foods from sorghum through food processing techniques?

Rooney

Sorghum can be used to make breakfast cereals, snacks, starch, sugars, and other products that are currently made from maize. The use of sorghum as an adjunct in European type beer is already happening in some areas, e.g., Mexico. New milling procedures will hasten the development of acceptable sorghum products.

Jambunathan

(1) In a sorghum breeding program, what should be considered as the optimum level of protein and lysine content? With respect to lysine, should it be considered as the percent of the sample or percent of protein or both?

(2) Has there been a careful evaluation of the relationship between yield level and protein content? If so, is it strongly negative?

(3) Is there a need to screen the sorghum germplasm for protein and lysine at ICRISAT in view of the work already done at Purdue?

Axtell

(1) Lysine expressed as percent of protein is most important to the plant breeder since protein levels in high yielding varieties will usually not increase or decrease much (approximately 10% in sorghum). The nurtritionist is interested in lysine as a percent of sorghum since this is most highly connected with nutritional value.

(2) Protein concentration is usually negatively correlated with grain yield in cereals. Selection for high protein alone will result in selection for factors which decrease endosperm size.

(3) Purdue cannot possibly screen all the entries in the rapidly expanding world sorghum collection. I would suggest that representative samples of entries should be selected for protein and lysine analysis and the task could be divided between Purdue and ICRISAT.

Jones, D.

Dr. Rooney said "if you do not have yield stability, forget about quality." This is almost the wrong way around. In Africa, high-yielding varieties (HW) are almost totally ignored because they are regarded as unpalatable. In India we are told that HW sell for 30% less than traditional varieties. Note that a farmer is indifferent between a variety that produces 43% yield increase for 30% price decrease and a variety that produces 11% yield increase for 10% price decrease.

Jones, D.

Has Dr. Axtell investigated the lysine content of whole diets in sorghum areas after local processing? I suspect that the nutritional problems of sorghum would look far less serious if he did this. Most people in sorghum eating areas eat beans or pulses as well and do process their food.

Axtell

This is correct. The data presented are base-line and are a comparable basis to that collected for other cereals. Data on whole diets and mixtures of diet should be collected.

Jones, D.

The use of the bran fraction of other cereals (maize, wheat) makes an important contribution to the economics of processing. Processing of sorghums will produce large quantities of high-tannin bran. Experience in Botswana shows that this is not suitable for addition to poultry feed. How can this sorghum bran be used to make a contribution to the economics of dehulling/processing?

Rooney

The bran from milling of sorghums is similar to wheat bran in that it is high in fiber, fat, and ash. It can be used in livestock feeds so long as care is used to formulate rations that are not too high in fiber. Sorghum bran in the USA is used in feeds similar to corn and wheat dry milling by-products. The bran from brown sorghum would probably be restricted for use in ruminant feeds.

Kambal

The fact that sorghum is low in lysine does not bother me as a sorghum consumer because sorghum is not eaten alone but mixed with vegetables, meat and milk. What is more worrying is the shift from sorghum to wheat in urban areas. I think the dehulling process is providing a breakthrough and is encouraging the consumption of sorghum substantially. The bran is not lost because it can be fed to animals to produce more meat and milk.

In the eighties, further effort is needed in novel food preparation to encourage more people especially in towns to continue to eat sorghum. More cooperation between scientists in the developing nations and those in developed countries is urgently needed. Provision of better research facilities in developing countries may encourage them to remain there and contribute to the combat of hunger.

Session 8

Socioeconomic Considerations

Chairman: V. F. Amann

Co-Chairman: T. S. Walker

Rapporteurs: N. S. Jodha

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Socioeconomic Considerations in Sorghum Farming Systems

D. W. Norman*

There is considerable heterogeneity in the farming systems found in the semi-arid tropic (SAT) regions of the world, where sorghum is usually the dominant crop. The heterogeneity consists not only of variations in the natural environment but is also due to considerable differentiation in the socioeconomic environment. The underlying objective of this paper is therefore to demonstrate in an illustrative fashion how an economist looks at the reasons for this diversity and the implications these have for work in sorghum breeding and agronomy, and for designing economic policies which affect sorghum growing regions. In examining these, two important, essential assertions are made:

1. Because of the low level of agricultural productivity and hence low incomes in the SAT regions, improvements in the overall income level cannot rely simply on redistribution of incomes or heavy subsidization by government but also have to be based on the development and adoption of relevant improved technology[1] in the sorghum dominated farming systems.
2. The major customers of improved sorghum technologies will be the mass of farming families and not plantations, government and private commercial farms, etc.[2]

Aspirations and Farming Systems

There is a certain universality in the aspirations of farming families and rural laborers which include as the most important elements income, effort avoidance and risk avoidance.[3] In economic terms this can be stated as rural people trying to increase their utility (satisfaction) which increases with income but decreases with effort or higher levels of risk. This can be restated as maximizing income for any given level of effort and risk, or alternatively reducing risk (or effort) for a given level of income.

Attempts to maximize utility take place within a set of constraints. It is not differences in aspirations but rather differences in the constraints which lead to the most important differences in farming systems. These differences can be grouped in a number of ways. For example, one convenient classification is as follows:[4]

1. A suitable or relevant agricultural technology is a way of doing things (combining resources to undertake crop, livestock and off-farm enterprises) in such a way that it is compatible with environmental constraints (both natural and socioeconomic) and as a result contributes to the aspirations of the farming families using it. The definition of a relevant improved agricultural technology is one that is adopted by farming families and helps them achieve their aspirations more easily through improving their efficiency (productivity).

2. Such types of production systems that are generally highly capital intensive, (i.e., highly mechanized) have had a bad history for many crops in Africa (IBRD 1981; Norman 1981).

3. Economists used to largely ignore risk considerations. However, recent research by Binswanger (1981) in India, Sillers (1981) in the Philippines, Walker (1981) in El Salvador, and Greeley (1981) in Thailand shows that farmers almost universally try to avoid or reduce risk.

4. Accessibility *to the socioeconomic determinants* (2. 3, 4) may be partially determined by community structures, norms and beliefs.

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1. Climatological and physical conditions.
2. Factor (resource) endowments and prices.
3. Exchange or market systems for inputs and outputs, and their related per unit costs and prices.
4. Information availability.[5]

The technology available for use by farming families is in essence determined by all of the above and is therefore of crucial importance in differentiating farming systems. In designing improved technologies, agricultural scientists have long recognized the importance of climatological and physical heterogeneity in determining their research strategies.This indeed is a big enough challenge in the SAT regions generally characterized by a harsh climate (with its limited, erratic and unpredictable rainfall) and poor soils. Nevertheless, in spite of this, it is not prudent to ignore the potential role of socioeconomic determinants (i.e., 2. 3 and 4 above) in designing relevant improved technologies. Many examples exist where ignoring the socioeconomic determinants has led to costly errors in research decisions.[6] Conversely, many economists have often failed to understand the implications of physical, climatological, or technological constraints for their economic policy recommendations.

However, farming systems are not only heterogeneous in terms of space, but can also be very heterogeneous over time. Changes in farming systems can occur over time as a result of alterations in the constraints faced by farming families. In West Africa, during colonial times much of the expansion in cash crop production (e.g.. cotton and groundnuts) was closely linked to the development of a bigger market for those crops as a result of the construction of the railways and roads (Hogendom 1976; Lele 1975)7 Farming families responded by devoting surplus-land and labor[8] to producing these crops with the help of traditional (indigenous) technologies.

Therefore, it is important to distinguish long-term determinants from those which change more rapidly. During 1982, many breeders will already be working on technologies for the 1990s. This, however, is not so much the case for agronomists and extension specialists who will have to grapple with shorter-run issues. Physical and climatic factors are virtually constant, while resource availabilities of countries and regions change relatively slowly. However, the other socioeconomic determinants of farming systems such as market systems and information availability, can change very rapidly. Therefore, provided that relevant research systems are in place, available improved technologies for sorghum and competing crop and livestock enterprises can also change rapidly. For example, development of the market and exchange systems on the input and output side is a crucial component of Green Revolution technologies with their clearly superior yields.

Because farming systems change, it is important to realize that descriptions of farming systems and the resulting perceived problems of farming families will not always be reliable guides for all research decisions. For example, developmental research decisions (i.e., research that has an intermediate to long-run pay-off) could be irrelevant if based on a constraint which conscious economic policy or the normal course of develop-

5. Traditionally experience which is a function of age is important. When external information starts to come to a region, communication facilities, education and extension services become important.

6. The reductionist commodity approach is a powerful research tool often used in developing improved technology. However, it has to be used with great care since it abstracts from the complexities of the natural and socioeconomic environment in which farming families operate. Incorrect specification of the environment in designing research priorities will result in the development of irrelevant technology. An example pertains to a technological package developed for cotton in northern Nigeria which was rejected because it involved planting earlier in the season. Although yields per hectare were higher than the traditional late planted cotton, farming families rejected the improved technology since its adoption would involve reallocation of labor from food crops used for home consumption which also yielded higher returns from labor at that time of year (Beeden et al. 1976).

7. This is generally considered to provide collaboration for Myints' Vent for Surplus model.

8. Some people question that there was always surplus labor. Rather, labor was sometimes reallocated from food crops to export cash crops to provide cash to pay taxes (Nicolas 1960; Kafando 1972).

merit could remove in the near future.' It is therefore necessary to interpret the descriptions of farming systems and the constraints they exhibit in a comparative fashion over space and time and to attempt to distinguish between constraints with long-term relevance and those which are more easily changed.

This paper concentrates on two major groups of socioeconomic determinants of farming systems that have already been mentioned, namely factor endowment, and market-exchange systems. After discussing the significance and implications of these for breeders, agronomists and economists, the topic of hybrids, which impinges on both the main themes of the paper, is discussed.

Factor Endowments

Although the levels, qualities and relative proportions of the factors of production (i.e., land, labor, and capital) have long been recognized as important in differentiating farming systems, they were not explicitly recognized as important determinants of the nature of technical change until the late 1960s (Hayami and Ruttan 1971; Binswanger and Ruttan 1978). Their Induced Innovation hypothesis reasons that technologies which increase productivity per hectare (i.e., yield-increasing technologies) are the major and cheapest source of growth in environments such as Japan or India with high population densities and hence low land/labor ratios. Conversely, technologies which primarily raise the productivity of labor (i.e., labor-saving technologies) have been, and are likely to be, the major and cheapest source of growth in land-abundant economies such as the U.S. and parts of Africa.

9. However, taking such constraints into account in determining research decisions is very important in farm located applied "downstream" farming systems research which seeks to improve the level of livelihood of farming families in the short to intermediate run (Gilbert et al. 1980). Under such conditions, research decisions on whether to attempt to overcome the identified constraints or avoid them through exploiting the flexibility in the farming system will depend on the nature or severity of the problem, and the potential solutions arising from earlier experiment station based developmental research, ability to influence economic policy and hence market and exchange systems, etc.

However, this is not the whole story. There are not only direct beneficial impacts of such technologies on the most limiting factors but there is also the possibility of indirect beneficial or adverse compacts on other factors used in producing the product. For example:

1. Yield-increasing technologies (e.g., improved seed, fertilizer; pest, disease and weed control, improved cultural practices) will, providing there is no change in the power source, usually increase labor requirements. As a result, depending on circumstances,[10] this can have either a positive or a negative impact on labor productivity.
2. Labor-saving technologies, such as draft animals and relevant equipment, can improve the productivity of labor, therefore permitting a larger area to be cultivated without a decrease in the productivity per hectare. Alternatively, labor-saving technologies such as herbicides cutting down on hand weeding, and draft animals and equipment reducing hand weeding and improving timeliness of operations can sometimes help increase the productivity of land.[11]
3. Obviously, yield-increasing technologies combined with labor-saving technologies are likely to have positive effects on both land and labor productivity.

In the following discussion these ideas are applied to sorghum farming systems of the SAT regions. Obviously, differences in land/labor ratios are most pronounced between countries in Africa and Asia but important differences also exist within African and Asian countries.

Land/Labor Ratios and Seasonality of Agriculture

The seasonality of rainfed agriculture on the SAT regions causes special problems involving labor peaks or bottlenecks during specific periods of the rainy season and underemployment particularly during the dry season. This is one of the reasons

10. Such as the degree to which yield is increased.
11. In Francophone West-African countries, incorporation of plant residues through deep plowing (*enfouissement*) with animal traction every 2 to 4 years is considered important in maintaining the productivity of land (Charreau 1978). However in India, Binswanger (1978) concluded that the use of tractors did not by themselves increase the productivity of land.

why a substantial percentage of farming families in the SAT regions supplement their income from agriculture through working in other occupations within or outside their home areas, particularly in the dry season.[12] The severity and nature of labor bottlenecks during the rainy season is determined in part by the length of growing season (the shorter it is the more peaked is labor activity), the type of technology being used and the power source (Norman et al. 1981).[13]

This pronounced peaking of agricultural activities in rainfed agriculture can complicate decisions concerning research priorities. Whether or not they should receive serious attention in research design will depend on the local situation particularly with respect to the land/labor ratios.

An example illustrating this pertains to one of the very common labor bottlenecks in the SAT regions involving weeding crops. Binswanger and Shetty (1977) have looked at the potential for herbicides solving this problem in India. An investigation of current practices revealed important information required in evaluating the potential value of herbicides.[14] They found farming families, sensitive to the adverse impact of weeds, rationally adjusted their weeding operations according both to the severity of the problem and to the potential payoff from weeding. In general, there were high levels of interrow cultivation with animal draft power and intrarow cultivation with hand labor. Although labor requirements for weeding operations were high, wage rates are low at such times. Consequently, even when all labor was costed at the market rate, budget studies on the cost effectiveness of herbicides indicated they were not competitive with current practices. Also much of the labor provided for the weeding operation is contributed by the most disadvantaged labor group in the Indian economy, namely female agricultural laborers from poorer families. Thus the societal costs of introducing herbicides, in terms of displacing labor, would be potentially very high. Not surprisingly these findings have led ICRISAT to deemphasize chemical weed control in the Indian part of its research program (Binswanger and Ryan 1980).

The conclusion could well be different in areas of lower population density (i.e., higher land/resident ratios and no landless laboring class). However, working with farmers in northern Nigeria, where such conditions do in fact prevail, Ogungbile (1980) still derived negative conclusions concerning herbicides. Incorporating his results into a dynamic linear programming model he found that the discounted net incomes over a 5 year period were highest for farming families using oxen, in the middle for those using hand weeding only, and lowest for those using herbicides. Although there were obviously problems with the herbicide technology packages and the farmers' application of them,[15] some legitimate doubts can be raised about their always being relevant even in areas where land/resident ratios are higher. It is likely, for example, that herbicides will only be profitable when combined with yield-increasing technologies that usually involve raising plant population densities and that, without herbicides, require more intensive weeding.[16] This in fact is currently occurring to a small extent in Mali Sud where yield-increasing cotton technology has been so widely adopted. An additional problem of using herbicides is finding those that are suitable for use in crop mixtures so characteristic of traditional systems of agriculture. A further

12. Such work patterns, that on a monthly basis show a negative correlation with agricultural activities on family farms, are in contrast to the farm laboring activities of the rural landless and land poor families in India where the level of such work is positively correlated with the agricultural cycle.
13. Labor bottlenecks can also be a function of the aggregation period used for analyzing the data (e.g.. week or month). This can on occasion create misleading impressions about the severity of the labor bottlenecks. Where timing is a critical issue (e.g., in the weeding operation) the aggregation period should be shorter.
14. Value was estimated by looking at cost effectiveness assuming that there were no yield effects of different methods.
15. For example, the herbicides applied prior to planting in the form of herbilizer were not always very effective. In addition farmers often weeded before it was really necessary, further decreasing the effectiveness of the herbicides in reducing labor inputs.
16. For example, in India Binswanger and Shetty (1977) found in some villages well over 50% of the sorghum fields were interrow cultivated with animal draft three or more times while about 30% of the fields were hand weeded two or more times. In contrast in northern Nigeria, many of the sorghum fields are not weeded more than two times while often no animal draft power is used.

problem in introducing herbicides is that it requires a good marketing system for distributing inputs, a subject which is discussed later in this paper.

Nevertheless, although doubts can be raised about the universal application of herbicides in areas where land/resident ratios are higher than India, and where there is no landless laboring class, it does not negate the attention that should be paid to labor bottlenecks in such environments. Agronomic practices and varieties that avoid such seasonal labor bottlenecks or do not accentuate them are likely to be more acceptable than those that ignore them, even if bottleneck considerations result in some sacrifice in terms of yield." Recent work by Matlon (1980) in Upper Volta has emphasized the potential problems of ignoring them. Preliminary results from testing the technological package revolving round the sorghum variety E35-1 indicated that delays in planting resulted because of the specification that plowing had to be done, a practice that is not traditionally done. Unfortunately, it appeared that this could not be circumvented by plowing earlier since farmers claimed plowing we/l before planting caused soil crusting making it difficult for seedlings to emerge.

High Land/Resident Ratios and an Open Land Frontier

High land/resident ratios imply the presence of unused land and, provided that the land tenure situation is not exploitive, the absence of a landless laboring *class.* In contrast to India such a situation prevails in much of Africa.

The very different factor proportions between the two regions imply different specifications as to what would constitute relevant improved technology. Traditionally, in areas with plenty of land, land extensive techniques, such as shifting cultivation in some countries in Africa, have been employed in which soil fertility regeneration is achieved through fallowing, and return per unit of the scarcest resource, labor, is maximized.[18] This rational traditional response is also relevant as a guideline for developing relevant improved technology. In such a situation, labor-saving technology is required that will increase labor productivity particulary at the times of the year when it is most constrained, thereby releasing labor to bring a greater area into cultivation. These technologies are particularly important in such areas where no reliable market for peak season labor exists." Indeed the labor market, to the extent to which it exists in such situations, resembles a sophisticated labor exchange system. For example, traditionally various social systems have often existed which have allowed more influential society members to *get* access to labor. Examples in countries in Africa would be village heads requiring villagers to work on their fields, complex family unit heads requiring individual family unit members to work on certain fields, etc.

In Africa, animal traction, which is particularly the province of agricultural engineers and sometimes animal scientists, has been perceived by some governments to be the major means of enhancing labor productivity.[20] However, the significance of increasing labor productivity has not always been perceived in the work of agronomists who, as the preceding section implied, are naturally orientated towards increasing the yield per hectare.

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17. For example, the results concerning cotton discussed in an earlier footnote led to developing recommendations for a later planted cotton, which although potentially lower yielding, required labor inputs primarily after the seeding bottleneck for food crops was past (Beeden et al. 1976). Unfortunately. as it happened, this strategy has not worked well primarily because of the rapid rise in prices farmers receive for selling food crops compared with that for cotton.

18. In the SAT region of West Africa, the "ring" cultivation system is a variant of the land extensive traditional system. Some fields usually near the residence *are* permanently cultivated and soil fertility is "maintained" through manuring, while fields further away are cultivated for a few years after which soil fertility is restored through fallowing (Marchal 1977).

19. For example, in northern Nigeria one study showed that on an average farm the marginal value productivity of labor (i.e., the value the last unit of labor contributed to production) during the weeding bottleneck period was substantially higher than the wage rate indicating that substantially more labor could profitably be employed during this period (Norman 1970).

20. This has been particularly the case in Anglophone West African countries. Sargent et al. (1981) have produced a useful review of animal traction in Francophone West African countries.

An example of the possible problem of this is an improved technological package (i.e., consisting of SK5912 sorghum, seed dressing, fertilizer, higher stand density, etc.) which was tested with a sample of farmers in northern Nigeria over a 2 year period, one of which was a drought year (Norman et al. 1978). As expected, there was a substantial increase of more than 80% in net return/hectare using oxen primarily for land preparation and some interrow cultivation. However, because of labor being more limiting than land, a more relevant criterion would be net return per man-hour.[21] Using this criterion, the net return per total man-hour was only slightly higher when oxen were used and estimated to be lower if only hand labor had been utilized. Two important implications of these results are as follows:

1. They indicate adoption of the improved technological package involved substantially more labor." In evaluating the possible severity of the problem of increasing labor requirements in a labor-scarce land-abundant region it is important, as suggested earlier, to determine when during the production cycle such increased labor is required. Increases occurring during periods when labor is underemployed obviously would be more acceptable than that occurring during peak periods. In the case of the improved sorghum package, almost 70% of the increased labor requirements were devoted to harvesting the increased yield, which constituted a new peak but on balance was probably a less serious one than the weeding bottleneck where timing is so critical.
2. The figures given above indicate that acceptability of yield-increasing technologies in labor-scarce areas may be increased through combining them with labor-saving technologies such as draft animals and equipment, thereby increasing labor productivity during labor peak periods. It is perhaps not surprising that in Francophone countries in West Africa, the introduction of animal traction has been perceived by governments as a means of land intensification when combined with yield-increasing technologies, although farmers often view it in a more traditional way as a means of increasing the area cultivated (i.e., extensification). Certainly in India animal traction has become closely identified with yield-increasing technologies.

These remarks appear to deviate from the premise at the beginning of this section that, in areas with high land per resident ratios, the most profitable way of increasing production is through expanding the area cultivated via labor-saving technology which increases labor productivity at labor bottleneck periods. However, the reason for the apparent inconsistency can be found by taking into account the following points:

1. The potential role of animal traction in land intensification does not necessarily negate its role in land extensification.
2. Unlike many parts of the SAT regions of the world, draft animals have a relatively recent history in countries in Africa and are therefore not part of subsistence agriculture."

Introduction of animal traction, particularly in West Africa, has accompanied the development of a market system because funds have to be provided, usually from selling agricultural produce, to purchase the equipment and often the animals. The strong emphasis on yield-increasing research and earlier often less emphasis on labor-saving research that would break relevant bottlenecks[24] appears to have led by design and default to support systems on the input side that have

21. Particularly for labor put in during the period(s) when labor was most limiting. However, in order to simplify the presentation, this discussion is confined to the net return per annual man-hour. In this particular example, the conclusions would not have changed if instead the return per man-hour put in during the labor bottleneck period (i.e., June-July). had been used.
22. That is, 138 more man-hours/hectare using oxen and 160 more man-hours/hectare using hand labor only.

23. For example, animal traction has a history of only about 60 years in West Africa. Exceptions do exist such as in the case of Botswana where cattle traditionally were owned by cultivators who considered ranching as their primary occupation.

24. For example, in a study in the Gombe area of northern Nigeria, Tiffen (1976) found that farming families utilizing animal traction for preparing more land ended up paying more hired labor for the weeding operation. In this case, suitable equipment was not available to satisfactorily overcome the most pressing labor peak (i.e., the weeding bottleneck).

emphasized yield-increasing technologies.[25] As a result, the most successful introduction of oxen has occurred where farmers have most widely adopted the successful yield-increasing technologies for export cash crops (e.g., cotton in Mali Sud and groundnuts in Sine Saloum in Senegal).

However, this situation does not negate the assertion that given the availability of relevant labor-saving technologies and relevant support systems permitting their adoption, there would be a greater response in terms of increasing the areas cultivated. For example, in Thailand where animal traction is traditionally part of the farming system, much of the increase in agricultural incomes in the last 20 years has come from area expansion although yields of most crops have declined as more marginal land has been brought into cultivation. In the northeastern part of the country cassava, being a less labor-intensive crop than rice and kenaf, has expanded rapidly.

Possibly, under such circumstances, breeders have a less clear role in developing improved technologies than agronomists and other scientists." Work emphasizing land-intensive development/conservation, irrigation," etc., is not likely to be adopted by farming families, but agronomists in conjunction with other scientists still have a significant role to play in developing practices that improve the productivity of labor such as intercropping and other practices which can help alleviate the weeding bottleneck period, improved planting systems, minimum tillage, reducing labor-intensive activities such as bird and monkey scaring, etc. However, as will be discussed later, the large distances resulting from high land/resident ratios make it likely that market systems, and hence access to support systems, might not be so well developed as in more densely populated areas. Consequently, under such circumstances improvements that require low dependence on the support systems are likely to be easier for farmers to adopt. However, in suggesting this, it is recognized that it makes it more difficult for agricultural scientists to develop improvements.

25. In many cases, the presence of tree stumps in fields has encouraged animal traction being linked with land intensification, since the destumping operation involves substantial investment.

26. Obviously, if breeders were to provide varieties attuned to such a resource base, stability of yield, resistance to diseases and pests and ability to withstand competition from weeds would be more important criteria than responsiveness to additions of nitrogen fertilizer.

27. This does not however negate the possible use of irrigation in the dry season when labor is underemployed.

Variations in Land/Labor Ratios Among Farmers in the Same Region

We have earlier suggested that inter-regional variations in land/labor ratios tend to be large. In the SAT they tend to be larger than intra-regional differences. A study undertaken by Ryan and Rathore (1978) in Indian villages showed that factor "ownership" ratios (i.e., ratio of "owned" land[28] to family labor) differ quite widely on large and small farms. However, factor use ratios differ much less among the groups although there is a large variation within the groups. The reason for the narrowing of the ratio is that factors such as land and labor are exchanged in rental markets. Ryan and Rathore (1978) suggest that current policies aimed at improving the access of operators of small farms to institutional credit markets will result in even more similar factor use ratios between small and large farms. In another study in the same villages, Binswanger (1978) found that both small and large farmers are moderately risk averse. Therefore, on the basis of both factor use ratios and risk aversion grounds, it was concluded that little could be gained from developing different improved technologies for small and large farmers. Rather, emphasis has to be placed on relatively profitable and stable technologies for all farmers and improved accessibility of small farmers to input support systems (i.e.. modern inputs, credit, and extension).

There are no directly comparable studies to ascertain whether the same conclusions would apply in countries in Africa. We would hypothesize however that in areas of high land/labor ratios where the amount of land cultivated is largely a function of the size of the family labor force, factor use ratios are not likely to differ significantly. In areas of lower land/labor ratios, sophisticated exchange/mobilization mechanisms for exchanging factors appear to give way to rental markets.

28. "Owned" is placed in inverted commas since generally in African countries individuals have usufructuary rights to land but do not actually own the land itself.

Although those would appear to encourage a move towards more equal factor use ratios, it may well be that because of the poorly developed input support systems, there is often inequitable access, therefore preserving differences in the factor use ratios. However, even if this is the case, the solution may often be more with adjusting accessibility to the support systems rather than developing different improved technologies, but the difficulties of doing this should not be underestimated.[29]

Exchange or Market Systems for Inputs and Output

The exchange and market systems are of crucial significance in determining the relevancy of particular improved technologies. The degree of market development is in turn influenced by a number of factors. All other things being equal, it is likely to be positively related to the level of development and negatively related to the physical distances to be covered.

Because of constraints imposed by the lack of a marketing system, farming families are then forced to be self-sufficient. It is not surprising that a self-sufficiency orientation is often more pronounced in areas of low population density where high land/labor ratios prevail and the costs of market development per customer are therefore relatively high.

The self-sufficiency orientation, usually implying an adaptation to low levels of production/income, is also an adaptation to the "costs" faced in exchanging goods and factor services. From the perspective of the self-sufficient farming family, these costs are deemed to be very high. For example, because of the effort required and low profitability levels, there may be little incentive to take small quantities of products to distant markets involving high transport costs in terms of money and/or time. Also, because of poor market integration, a strategy of producing cash crops may be perceived as too risky with too little to sell in drought years when food prices are also high. Nevertheless, seasonal hunger or the hungry gap which occurs at the beginning of the rainy season (Raynaut 1973) is still a major problem in many such areas but is probably often accentuated when market structures start developing and some reliance is placed on what is inevitably at the beginning a poorly developed and therefore inefficient system. The occurrence of the hungry season at such a time has a serious impact on labor productivity with a reduced calorie intake resulting in weight loss and reduced resistance to disease (Chambers and Longhurst 1979). Unlike in West Africa, where this hungry season occurs at the busiest time of the year, this period in India appears to be more common during slack periods in the agricultural cycle. In India, the inequitable land distribution and well developed labor market enables landless laborers to find work during active periods in the agricultural cycle.

Costs and marketing risks decline with improvements in communications, transport, and market integration. For example, a drought affecting sorghum producers in the United States does not also raise their food prices, which are largely independent of growing conditions in sorghum producing regions. Low transport costs and high integration into the national and international market imply that developed country farmers produce almost exclusively for the market and are often more highly specialized than their counterparts in developing countries. SAT countries differ in the extent of market integration of their economies. In India, for example, there is a high degree of domestic market integration but a low degree of international market integration. In Thailand, there is a high degree of market integration both domestically (i.e., except for distant regions) and internationally, while integration is low in both areas in many parts of Africa. In general, however, the degree of market orientation and integration is rising everywhere.[30]

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29. Because of limited resources, governments which usually provide such support systems find it difficult to provide them at the level that would be desirable. Consequently, access to such systems is often confined to the more influential and economically powerful farming families. Also problems are developing with the adoption of certain types of technology. For example, in Mali in recent years, the prices of cash crops have increased less rapidly than prices of animals and equipment (CRED 1976). Thus adoption of animal traction has slowed down creating an increasing dichotomy between those who already possess animal traction and those who do not (Ernst 1976).

30. Although rising energy costs are causing setbacks in this trend particularly in thinly populated areas (e. g., areas away from the line of rail in Zambia).

Farm Level Self-sufficiency

The higher the degree of subsistence orientation, the greater is the concentration on food crops. In countries in Africa, the traditional large extended family unit[31] was compatible with this food self-sufficiency orientation and ensured survival in the absence of formal external labor and credit markets. For example, large family units enabled control over a larger supply of labor and other resources.

With a food self-sufficiency orientation together with very limited opportunities of earning cash from other sources,[32] cash available for buying nonagricultural commodities or agricultural inputs is extremely limited. In addition, under such circumstances, the problem cannot be alleviated through credit markets which are at the best poorly developed.

Consequently, implications for developing relevant improved technologies under such circumstances are as follows:

1. There should be an emphasis on food crops that are acceptable locally in terms of taste and storability.
2. The technologies developed should have minimal dependence on modern inputs distributed through the market system, while other inputs required for their adoption should be within the capacity of the family unit itself (e.g., labor).

There are also temporal implications in terms of relevant improved technologies. This is because of the limited, and often unreliable, growing season for rainfed crops in the SAT regions, resulting from low levels of rainfall which are combined with erratic inter- and intra-annual distribution. Balcet and Candler (1981) based on work in northern Nigeria have concluded that farming family strategies at the beginning of the growing season tend to be very risk averse and aimed at fufilling food self-sufficiency. This need dominates during the period between the start of the rains to the germination of the first food crops. If the rains are good, this period of concern will usually end at the first weeding. However, if the rains are bad, such strategies will dominate until much later in the season. After this critical stage is past and food supplies are ensured, then given the right incentives other crops might be grown (see next section).

Because of this seasonal sequence there are additional implications in terms of developing relevant improved technologies for regions where food self-sufficiency dominates actions. Three of these are as follows (Balcet and Candler 1981):

1. Technologies that are divisible and flexible, both as regards the timing of application and intensity of use, are more likely to be readily accepted because they can be adjusted sequentially depending on the type of season.
2. Technologies giving results at the critical germination period, when farming families are particularly focusing on indicators that would mark the end of the safety-first period, are likely to be more readily adopted.
3. Improved technologies often require rearranging the whole farming system to adjust to changing relative scarcities in labor, time and/or other resources. Because early in the growing cycle farming families' behavior is more risk averse, improved technologies that require rearrangement of resources at that time are unlikely to be adopted.

Almost everywhere if a food self-sufficiency orientation exists, it is in a state of transition. Improvements in transport systems and hence marketing systems can have rapid, profound, and far-reaching effects. Thus it is believed that long-term breeding efforts emphasizing a subsistence orientation are a less fruitful area of research investment than short and perhaps medium term agronomic research.[33]

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31. Such a unit, sometimes called a complex family unit, consists of more than one married man plus dependents. This is in contrast to a simple nuclear family unit where only one married man plus dependents are found.

32. However, a common strategy to overcome this problem in West Africa has been for individuals to go on a short seasonal migration during times when activities on the family farm are at a low ebb (Roch 1976; Peil 1977).

33. Hard decisions have to be made concerning the allocation of scarce research resources. Because many local varieties often appear to have some unrealized potential, and support systems can change very rapidly, it is believed that long-term breeding efforts may have a higher eventual payoff where input support systems are readily available.

Changes from Farm-level Food Self-sufficiency

There is often a definite sequence of agriculturally related activities following the development of improved transport systems. Initially, at least in West Africa, markets for agricultural products have developed with considerable emphasis on export cash crops produced, using traditional techniques. As surplus resources, particularly labor and sometimes land, were used up, increased emphasis was placed on disseminating improved technologies together with the requisite support systems in terms of modern inputs, credit and extension services. These have tended until recently to emphasize export cash crops. The lack of favorable marketing policies[34] for food crops and relevant improved technologies for substantially increasing their production has no doubt contributed to their lack of market integration especially with respect to food crops. Thus a food self-sufficiency orientation continues to be of overriding importance in the poorer areas where no export cash crops are possible, while a confused mixture of food self-sufficiency and income maximization appear to prevail in many areas where export cash crops can be produced. However, a shift away from food self-sufficiency towards an income maximization orientation has a profound effect on the lives of farming families and also has important implications in terms of what constitute relevant improved technologies.

As we suggested earlier, complex family units are compatible with a food self-sufficiency orientation. However, the development of market systems and access to new information via the extension services reduces the premium formerly attached to self-sufficiency. As a result of losing some of their relevance, complex family units eventually often disintegrate into smaller nuclear family units, a trend which is currently occurring throughout West Africa.[35] Two examples illustrating the ways in which development of market systems can bring about such changes are as follows:

1. Increased agitation for more financial independence on the part of individuals within complex family units results in greater proportions of fields under the control of the family head (i.e.. common fields) being allocated for individual use, thereby subverting the possibility of attaining food self-sufficiency and decreasing the benefits of such units staying together.
2. For a number of reasons, institutional credit programs are often directed only at family heads (e.g., Senegal).[36] This can therefore mean differentiation in terms of types of technology applied on the common fields under the control of the family head and those under the control of other family members (Venema 1978). This undoubtedly would encourage the mutiplication of family heads through breakdown into smaller nuclear family units.

Therefore, development of market structures in aiding the development of product and factor (e.g., labor, credit, and sometimes land) markets opens up opportunities for people to benefit individually. Regardless of whether this is good or bad, it is emphasized that since it is likely to continue, it has important implications in terms of relevant improved technologies.

The shift towards an income maximization orientation permits a degree of commercialization in the farm enterprise through the marketing of products the proceeds of which, together with funds obtained through institutional credit programs, can be used to purchase modern inputs, extra labor, equipment, etc., required for the adoption of the improved technologies. Thus the potential for developing improved technologies which bring about substantial increases in productivity are much greater than under the more restrictive conditions surrounding a food self-sufficiency orientation.

34. For example, in West Africa, many governments, in a largely unsuccessful attempt to keep food prices low for the politically volatile urban consumer, have entered the food crop marketing system, and paid low producer prices for food crops (IBRD 1981). However, this has not prevented high retail prices for food crops being charged in rural areas towards the time of the harvest period.

35. For a brief review of the reasons given in the literature see Norman et al. (1981). We would suggest that many of the reasons can be related to the rationale presented in this paper.

36. For example, from the perspective of the loaning agency, overhead costs are reduced through dealing with one member of the family.

For reasons explained earlier, some farming families may have a mixture of food self-sufficiency and income maximization objectives. For example, returning to the northern Nigerian study undertaken by Balcet and Candler (1981), they suggest that once farming families feel the critical stage for fulfilling food needs is past in any particular year, they will slowly change their objective to one of income maximization at some specific level of risk. Farming families may during this period be more willing, in contrast to earlier in the season, to accept improved technologies that require considerable reallocation in resources. In addition a degree of income maximization can make cash available[37] to purchase modern inputs for those crops which provide food self-sufficiency.

Hybrid Sorghum

Recent success with the introduction of hybrid sorghums in India has led to increased discussions about a major emphasis on hybrid sorghum breeding programs in West Africa. Obviously, an economist is not qualified to judge the technical feasibility of such a strategy leading to successful results. However, in view of the subject matter of the paper, the potential value of such a strategy from a socioeconomic perspective is discussed briefly.

There appear to be two important characteristics that have helped to ensure the success of hybrid sorghums in India. These are as follows:

1. As a result of exploiting heterosis, quantum jumps were achieved in yields of hybrid sorghum compared with much more modest increments in yields earlier achieved by resource management with local and local improved varieties (Rao 1981).
2. Although, as would be expected, higher yields were associated with higher variances (Mehra 1981), the increase in variances was not very great and was well within the measured risk aversion of farmers (Barah et al. 1975) and, compared with other varieties, generally proved to be stochastically dominant at all levels of fertilizer application.

Judging by the widespread adoption of hybrid sorghums in India, it is apparent that their superiority has been maintained when translated into net return terms. It is obvious that hybrid sorghums should receive serious consideration in West Africa, only if it is feasible to solve the technical problems and as a result to produce hybrids with similar advantages as in the Indian setting.[38] However, assuming these can be produced, what would be the socioeconomic conditions required for their adoption? Three crucial ones would be as follows:

1. Because of their yield increasing characteristic they would be most relevant in areas faced with a scarcity of land, that is where land/labor ratios are low.
2. Annual purchasing of seed plus other modern inputs will mean that hybrid sorghum technological packages would be limited to farming families who have a source of cash, either from selling crops or from livestock or an off-farm enterprise.
3. A strong input support system for the multiplication and distribution of hybrid seeds, distribution of fertilizer, etc., would be required.

Currently in West Africa, there are still relatively few areas where population densities are high and therefore yield-increasing technologies would naturally fit. Also input distribution systems are generally poorly developed particularly with reference to food crops, although World Bank supported Integrated Agricultural Development Projects have often helped improve the situation in recent years. Finally, apart from the success with hybrid maize in Kenya (Gerhart 1975), there has been little experience in countries in Africa with hybrid seed multiplication and distribution systems.

However, this does not necessarily mean that a hybrid sorghum program might not be relevant in the West African setting for the next decade. Population densities are increasing at alarming rates in some parts of West Africa and carrying capacities of land are in the danger of being exceeded. Also input support programs could be implemented fairly quickly if promising technological packages emerged. Therefore, from a socioeconomic perspective at least, there would

37. Of course it is possible cash could come from other types of enterprises, such as livestock and off-farm employment. In such cases marketing of crops to provide cash would not be so important.

38 We recognize that there is currently considerable debate as to whether the technical problems can in fact be solved.

appear to be merit in strengthening a long-term hybrid sorghum breeding program for West Africa in anticipation of producing results towards the end of the decade, when socioeconomic conditions are likely to be closer to what are required for their adoption.

Conclusion

This paper has attempted to provide some understanding of socioeconomic sources of heterogeneity in farming systems. Socioeconomic sources have systematic effects just like differences in the climatological-physical conditions. Therefore, it is as wrong to ignore such sources of heterogeneity as it would be to ignore the climatological-physical conditions.[39] Consequently, because of the heterogeneity these create, severe limitations are placed on the potential transferability of systems, practices and even components of improved technological packages. Nevertheless, in addition to climatological-physcial sources of variation, socioeconomic sources of variation must be taken into account if limited research resources and 'more generally resources for agricultural development are to be utilized more effectively.

In terms of Africa, a recent World Bank report (IBRD 1981) has recommended that limited developmental funds should be concentrated on the more favorable areas where both export cash crops and food crops are grown. The report recommends that attention to the poorer areas where only sorghum and millet can be grown should be delayed pending the availability of relevant improved technologies for those crops. The challenge is great and can be addressed only by a relevant combination of a long-term breeding program, with the eventual potential of a revolutionary impact with agronomic work within a shorter time frame which will result in evolutionary improvements in currently practiced farming systems.

39. An appreciation of this has come a long way in the last decade or so. For example, it is interesting to note that in the predecessor to this symposium (Rao and House 1972), there was no section devoted to socioeconomic considerations, although the concluding remarks by House indicated that socioeconomic issues were raised in earlier discussions.

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Grain Marketing in the West African Semi-Arid Tropics

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The Sahelian drought of 1968-73 aggravated and drew world attention to the already precarious nature of this region's food situation. Nutritional and caloric deficiencies plague the people of this area (90% of whom are rural). Production of sorghum and millet, the dietary staples, is regionally uneven and generally of a subsistence nature. Transportation is difficult and costly and storage, at all but the village level, generally inefficient. Experts agree, however, that food self-sufficiency is an attainable goal. All aspects of the food system, production, marketing, distribution, and storage are implicated in achieving it.

Considerable research has been done and continues on means to increase production of the principal food crops. It focuses on such technical aspects as changing the cultivation techniques and using improved varieties of seed for increasing yield. Founded in the belief that prices, acting as market signals, also affect the quantity produced, policy makers have been interested in the marketing behavior of peasants and the functioning of grain markets. In response to these concerns, research has been done on different aspects of the grain marketing systems of the West African Semi-Arid Tropics (WASAT), the Sahelian countries.

The purpose of this paper is to put into perspective what is known about these marketing systems and to make recommendations for the direction of future research in this area. The major conclusions are that marketing research must take into account the regional diversities of the national marketing networks and consider marketing as one part of the food system. From this perspective it can identify important constraints to improving the efficiency of this system and respond better to the needs of policy makers.

We begin with a descripition of marketing arrangements, including a summary of the major marketing channels. This is followed by a review of the findings of marketing studies done in the WASAT. We draw two major conclusions which are supported by these studies and reflect the authors' personal experience in this area. These conclusions suggest the major issues for marketing research in the 1980s and a methodological approach. The paper ends with a reiteration of all the conclusions.

We are wary of making generalizations about the marketing systems of the WASAT. Each nation has its indigenous market structure, with its regional and ethnic diversity and each government its own brand of state intervention. This coupled with differences in infrastructure (roads, warehouses, and personnel), crop mix, prices, and other important variables, makes each country a special case.

Certain characteristics, however, seem common to all of the countries and are important for developing a general understanding of marketing in this zone. Each of the countries has private and state marketing systems which coexist. Although the state has a legal monopoly on grain marketing, except in Mauritania, it handles only about 20% of marketed grains. Private trading thrives. Food crop production is concentrated in cetrain areas of each country. Consumption needs are concentrated in large urban areas and rural areas that have production deficits. Redistribution is costly and difficult. The dimensions of the problem in a

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regional sense are well known. It is time to move on from these generalities to the specifics of each case.

Marketing Arrangements[1]

Despite the importance that food crops play in the economies of the WASAT, prior to the drought of 1968-73, they were almost completely neglected in government planning. This did not mean that there were no effects on the food crops. Rather, they suffered from a policy of neglect. In particular, export promotion policies which encouraged cash crops resulted in a deterioration of the food crop sector.

The 1970s witnessed some important changes. There was a general shift in goverment policy objectives from producing cash crops to food crops, as emphasis was placed on food self-sufficiency. In the realm of production, extensive research began to develop improved seed varieties and better technical packages for sorghum, millet, and maize. Concurrently, these governments became aware of the potential role of marketing in general agricultural development, specifically for cereal grains. The first result of this awareness (whether for better or worse) was attempts at extensive public intervention in grain marketing. Each country set up its own grain marketing board: Mali-OPAM, Mauritania-OMC, Niger-OPVN, Senegal-ONCAD, and Upper Volta -OFNACER.[2]

These state agencies were established for essentially the same reasons. The production and commercialization of the staple food crops are politically as well as economically strategic sectors of the economy for state intervention and control. The economic justification for such intervention rests in the long held belief that traditional traders are monopsonists, and that this coupled with their dual role as local moneylenders, put them in a strong position to exploit the peasant both as a producer and as a consumer. His need for cash soon after harvest forces him to sell to monopoly traders who offer low prices for grain. Similarly, his indebtedness to this same trader strengthens the trader's hold over him.

In sum, it was (and still is) believed that private sector grain trading was heavily monopsonized and monopolized, and that economic and social forces serve to strengthen this structure and increase the inequitable division of the benefits of trade. Thus, the grain boards have as their stated objectives: (a) to offer "fairer" prices to producers while offering a reasonably priced supply of grain to urban consumers; (b) to stabilize intra-annual producer prices; (c) to establish and regulate security stocks; and (d) to organize grain exports. The next section is a brief description of both state and private marketing channels.

Major Marketing Channels

Each of these countries now has a dual market system: state-run marketing and private trading The particular mix between the two depends on a number of factors, but in each the two systems interact. Most frequently the literature groups the market participants into such categories as: assembler, transporter, wholesaler, and retailer. Individual agents, however, often fulfill more than one function and each category has a different meaning when put into different marketing channels. The relations between the agents and the number and specific tasks depend on the region and the channel.

More useful than categorizing agents, for understanding the way in which grain is marketed, are descriptions of the different types of channels through which the grain flows.[3] The marketing channels can be divided into two basic categories: grain that bypasses the market place and grain that passes through it. Within the second group are two subgroups: privately and state traded grain. Since all the grain that is marketed by the state passes through the market, this section is divided in two: state marketing arrangements and private sector trade. The latter includes grain that bypasses the market place.

1. For an in-depth presentation of marketing arrangements and pricing policy in the CILSS countries, the reader is referred to CILSS (1977).
2. Nigeria has had a marketing agency for food crops since before independence. It is virtually ineffective in the area of grain marketing. It is not discussed in this paper.
3. For an in-depth discussion of the functions of different agents and for a description of the various marketing channels see Wilcock and Ouedraogo (in press).

State Marketing Arrangements

Each country of the WASAT has its state controlled grain marketing agency. The particular formulae differ, but the concepts are the same. The state buys grain either directly from villagers or from traders who have been given the government stamp of approval (agreement). Grain is bought at a fixed price throughout the country, redistributed, and sold by the marketing agency at another fixed price.[4]

A brief description is given below of the specific public sector marketing arrangements in five countries of the WASAT.

Mali

Until December 1980, grain commercialization in Mali fell under the jurisdiction of OPAM (Office des Produits Agricoles Maliens) which in 1965 was given a monopoly for the purchase and sale of staple cereal grains.[5] OPAM relied on the agricultural extension units (operations) and the village cooperatives for its collection operations. It was responsible for financing the buying campaign, for transporting the grain from regional collection points and distributing seed to producer cooperatives. OPAM itself (its agents) had no direct contact with either the producer or the producer cooperatives. All transactions were done through an intermediary. Grain prices were set by the national administration, and regional and village quotas were set by local government and agricultural agents in consort with the village chiefs.[6]

Mauritania

The Office Mauritanien des Cereales (OMC) was created in 1975 as a result of an artificial market scarcity of millet and sorghum after the drought. Its mandate was to contribute to implementing a rational policy for supplying grain to the domestic market. The intention was not to monopolize grain trade, but to stimulate competition and to increase the flow of grain between deficit and surplus zones. At first the government tried to set prices, but the initial endeavor resulted in prices that were too low, thus forcing OMC to compete at market determined prices. SONIMEX (Societe National d'Import et Export), the national import monopoly, meets the excess demand for rice by importing it. Millet and sorghum imports, however, are in the private domain.

Niger

In Niger, OPVN (Office de Produits Vivriers du Niger) has the legal monopoly on the marketing of cereals. It does not buy directly from the producer, but acts as a wholesaler. Official prices are set uniformly by the Minister of Economic Affairs throughout the country for purchases and sales.

The primary collection is done by village cooperatives and approved traders. The traders must buy at legal minimum prices and sell to OPVN at this price plus a fixed commission, although the means for enforcing the minimum are limited. Village cooperatives buy from their members. Both the cooperatives and traders are financed through the subprefects who receive money from the UNCC (Union National de Credit Agricole) which receives its funds from the Agricultural Credit Bank (CNCA). It is the subprefects' job to approve traders, assign them different markets, and to dispense funds. Traders deliver grain to the OPVN warehouses and trucks pick up the grain from the local cooperatives.

The grain is sold directly from the OPVN warehouses. Because the demand for cheap grain often exceeds supply, a rationing system exists. Purchasing by government employees is facilitated by bulk ordering.

Senegal

From 1975 to 1980, ONCAD (Office National de Cooperation et d'Assistance pour le Developpement) had the legal monopoly for the primary collection of millet and sorghum in Senegal. Until 1975, trade in millet and sorghum was officially in the hands of private traders, ONCAD, which had a monopoly for groundnut purchases and sales, bought some millet and sorghum to sell to producer cooperatives in grain-deficit areas. When it existed, it depended on local cooperatives to purchase from producers. It collected grain weekly and stored it in regional warehouses. Some grain was allocated to a security stock and the rest

4. Mauritania is a notable exception to the uniform pricing rule.
5. For a brief critical study of OPAM see Berg (1980).
6. OPAM was forced to give up its grain marketing operations due to pressure exerted by the IMF and several aid donors.

to commercial sale. ONCAO sold to producer and consumer cooperatives, stores, and approved private traders. As with the other public sector marketing agencies, it was the legal importer of grain. Official prices were fixed for both purchases and sales.

As of October 1980. ONCAD was disbanded because of operational inefficiency and financial irregularities. Its function as the provider of agricultural inputs was taken over by a newly created agency. SONAR (Societe National d'Approvissionment Rural). Thus far its function as a marketing agent for millet and sorghum (as well as for other products) has not been replaced. Commercialization of these crops is now officially in the hands of the private sector.

Upper Volta

In 1971, OFNACER (Office National des Cereales) was created and given a legal monopoly for the sale of grain to consumers. In 1974, the agricultural extension units (ORD—Office Regional de Developpement) were given a monopoly for purchasing for OFNACER. They subsequently withdrew from this job because of insufficient personnel and equipment. OFNACER now buys either with its own agents, or through traders who it specially licenses (agree). The buying campaign opens after harvest, once the purchase and sale prices have been fixed by the government. It buys in selected areas, transports and redistributes the grain. It has warehouses in all major centers from which it is supposed to sell. In typical years, OFNACER purchases about 20% of the marketed grain. Before 1971, grain trading was legally entirely in the hands of private traders; since then, although OFNACER has a legal monopoly, there are no efforts made to enforce it. It buys where it can in areas where the free market price is lower than the official one.

The following general characteristics of government grain trading are common to these five countries. The government plays the role of a wholesaler. Only in Upper Volta does it buy directly from the producer. In general, there is at least one intermediary between the producer and the marketing agency—a cooperative, trader, or extension unit. Grain that it purchases from the middleman is transported to regional or central warehouses and redistributed according to priorities of the government or perceived need. Much of this grain is destined for government employees (especially urban).

Government price policy, except in Mauritania, involves setting fixed, uniform producer and consumer prices. Exactly how the prices are determined is not clear. Each of the marketing agencies has incurred large deficits since its inception. No attempt is made here to assess the successes and failures of these various schemes.

Private Sector Trade

In all of these countries the majority of commercialized grain, i. e., 70-80%, flows through the private sector. A certain portion of this grain is traded through transactions that take place outside the markets, through "house-trading" (direct contact between producers and consumers) or by way of intermediaries who conduct business independent of the market and are often linked, one to the other, by special arrangements (financial and other). The initial transaction often takes place in the village; from there, the grain may continue to bypass the market or enter it. Most privately traded grain, however, does pass through the market. Five major marketing chains can be identified:

1. Direct from producer to consumer:
   This involves the producer marketing his own product, generally in small quantities, and the consumer purchasing directly from him at the market.
2. Producer to local trader to consumer:
   The producer sells his grain in the market to a local trader, who purchases from many producers. He may store it for a time, and then sell it to consumers, or turn it over the same day.
3. Producer to local trader to assembler to consumer:
   This chain is the same as above, but involves an assembler who purchases in bulk from many local traders and retails the collected grain elsewhere.
4. Producer to local trader or assembler to national trader to the consumer:
   In this chain, instead of retailing the grain, the assembler sells it to a national trader (one who assembles grain from many regions) who in turn retails it.
5. Producer to local trader or assembler to national trader to different regional traders to local trader, to the consumer: This chain, the longest, essentially moves the grain into a large urban area, and back out to the rural area.

In ail of the above chains any one person (trader) may be assuming more than one function, and may be participating in more than one chain at a time. Benefits from marketing generally accrue at each step along the chain. The particular market structure for each transaction determines the division of the benefits between the participants. The degree of concentration varies from market to market and between regions.

Traders purchase mostly on their own account, sometimes for the state. They are rarely specialized in one sort of trade, but rather function as conglomerates. In rural areas they are farmers as well as commercial agents. In towns they also operate stores and mills. The largest traders have their own transportation and distribution networks. All traders are potential, if not actual, moneylenders.

When the state intervenes it assumes part or all the chain between the producer and consumer. Its effectiveness depends on how much it takes over. The strongest benefits of the scheme accrue to the people who deal directly with the state agency and not necessarily to the participants at the ends of the chain.

The two systems, private and public, interact in several ways. In none of the countries does the state control all grain trading, and in most cases it does not even control one entire channel. Thus. traders, producers, and consumers must decide how to react vis a vis the state agency. In areas where the marketing board operates, free market prices reflect this increased competition. Traders must behave so as to either minimize its effect on their trade, or maximize the advantage they can take from it.

Marketing Studies

The marketing studies of the late 1960s and 1970s focus on testing the hypotheses under which the state marketing boards were justified, evaluating their performance, and describing the way in which the two market systems function and interact. Those undertaken by economists concentrate on assessing the competitiveness of the marketing system and the effects of the system on production, using the structure, conduct, performance paradigm. Anthropologists focus on the debt cycle and the social relationships that are a part of trade.

Several reviews of the literature and annotated bibliographies exist: Arditi (1975, 1978), Harriss (1978) and CILSS (1977). The sheer volume of works on this subject attests to the interest and effort devoted to it. The most extensive research in the region has been done in Nigeria, beginning with Gilbert (1969), Jones (1972), and Hill (1971, 1972). These have been followed by numerous studies on the trade of specific producers as well as production studies that include a marketing component. Research in other countries developed along similar lines, though it has been less extensive.

The CILSS (1977) study of marketing, price policy, and storage of cereal grains in the seven countries of the CILSS is an overview of the specific marketing arrangements and policies of the region. The point of the study was to diagnose the problems in the area of marketing, including an evaluation of the existing state interventions and to suggest solutions. One of its major conclusions and recommendations is that there is a lack of, and thus need for, data about the marketing behavior of individual farmers. Since 1977 researchers have responded to the plea by Berg (1980) by concentrating on village-level behavior, as opposed to just looking at national or regional aggregates. The farming systems methodology emphasizes the importance of the rural economy as a system, each of whose parts plays an important role in the operation of the whole. Thus, while not always the primary focus of a village-level study, marketing is now being looked at as part of this larger system.

The marketing literature falls into two categories: that which concludes by supporting the aforementioned hypotheses, and that which refutes them. The battle lines have been drawn along ideological lines, with CILSS (1977) and Berg (1980), and Harris (1978, 1979), respectively, representing these polar interpretations. One group of studies using an adaptation of the "structure, conduct, performance" (SCP)[7] analysis applied to price data concludes that trade is basically competitive. The other, using a more anthropological approach, interviewing farmers and traders about their relationships, concludes that trade is not competitive, and that the marketing system aggravates the already marginal status of the poorer groups in society.

7. For criticism of both the method of analysis and its application to West African data, see Harriss (1979).

interpretations can be given to the critique. On one extreme, some may conclude that the goals are unattainable even on a theoretical level—that the existing market structure is such that state intervention is not necessary and. even stronger, that it aggravates the perceived inequities. It can also be taken to mean that the goals are incorrect—that other goals are more important and that they should be redefined. There are still others who believe that the goals are genuine and attainable, but that the policies undertaken to achieve them have been ill-designed.

The specific conclusion drawn depends largely on the ideological perspective of the writer. Three distinct points of view exist: The free marketer believes that the market, unfettered by government intervention, distributes goods most efficiently. The practical free marketer prefers the free market solution, but admits that the government, for political and other reasons, will not easily dismantle the elaborate grain marketing structures it has erected. The third point of view is that an economically efficient solution is not most important, but that the equity goal of the government to offer stable, fair prices to producers and stable, affordable prices to consumers is correct. Generally, the writers pick and choose among the evidence to support their belief.

Two important points emerge from these discussions." The free market perspective, alone or coupled with institutional realities, suggests that state intervention, for the purpose of stabilizing prices and redistributing grain, is (a) not necessary and (b) not practical, because of insufficient infrastructure and trained personnel. It is not an efficient solution to the problem. Here the first two perspectives diverge. The second joins the third and admits that the West African governments have a strong political commitment to state intervention. In the long run, these economies may be better off with no marketing agencies, but in the short run it may be difficult to eliminate them. They conclude that the important questions are: what has gone wrong up to now, why, and what, if anything, can be done (by changing their goals and/or their methods of operation) to make them effective and efficient.

The feasibility of trying to attain food self-sufficiency by offering low consumer prices and adequate producer prices must be examined. Are they conflicting goals? If so, which is more important and how can it best be attained? What are the trade-offs? The role of the public sector in grain marketing must be reassessed, and alternative marketing arrangements (public marketing boards, private trade, and farmers' cooperatives) in solo, or in combination, considered.

The wealth accumulation of private traders seems distasteful to all but the traders themselves; however, it is also recognized that their profit motive makes them extremely efficient, and they are likely to continue accumulating wealth if given the chance. Is there some way that the private sector and entrepreneurial initiative can be fitted into the development scheme, instead of trying to squelch it? Can the private grain traders, for example, be encouraged to participate in the distribution of inputs?

The last issue deals with changing consumer preferences. Should shifts in taste to more western, nonindigenously abundant goods (rice and wheat products—bread and macaroni), be encouraged or discouraged, and how? This question is as equally important from a production as from a marketing perspective. Price policies, research priorities, and the emphasis on developing improved technologies for one grain versus another, affect the relative quantities of different grains produced. Irrigated rice, for example, may be less risky, but it is also more costly in terms of capital resources. The consumption effects of production policies cannot be overlooked. Are items such as irrigated rice just a substitute for a cash crop?

Research Priorities

Future research on marketing in the WASAT must be designed to provide the broad range of information about both peasant and trader behavior patterns, market structure and regional flows of grain that is necessary to make effective policy. Unfortunately, research that is not either policy oriented, or motivated by policy concerns is unlikely to meet the policy maker's needs. This results in policy with insufficient data or necessi-

11. All three perspectives are agreed that there is a role for the state in constituting and controlling security stocks. It is a public good—an acceptable and desirable domain for government intervention and one that would not be fulfilled otherwise. The free marketer believes the government should concentrate all its efforts here.

tates at least a partial duplication of the research effort in order for the policy maker to have the right information.[12]

As in any research, paring down the problem to manageable proportions is essential. Research of the 1970s concentrated on specific marketing regions, resulting in considerable information about specific regions, to the exclusion of an understanding of the countrywide marketing system—the links and how they fit together.

Regional diversity is an important dimension of the problem of food distribution. Regional differences in trader organization and behavior, market channels, and peasant output and commercialization patterns are significant. In the initial phase of research for the 1980s, basic information must be gathered from all regions of the country so that the areas selected for the intensive part of the research can be chosen to represent the range of marketing/production situations that exist. Specifically, information is needed on the entire hierarchy from the producer through the urban traders and back out to the consumer, both urban and rural.

For the most intensive part of this type of research, data must be gathered at several different levels: the market, individual traders, and peasants. Market data should include frequent and regular information about prices and quantities. Information about market structure is particularly important: trader organizations, price setting techniques, market control and differentiation practices. For individual traders, in addition to the prices and quantities of sales and purchases, data on operating procedures, methods of reducing costs, evaluating and reacting to risks and making decisions are essential for understanding why the market takes on its overall characteristics. At the most microeconomic level, data on the individual producer/consumer's behavior with respect to sales, purchases, and consumption complete the picture. This can be gathered through a combination of formal questionnaires and informal discussions.

We also suggest that in the process of doing basic production research, certain marketing information should be collected as part of the interviewer's and researcher's regular inquiries. Because so much production research is conducted on a yearly basis, the production researcher has the possibility of collecting an enormous amount of data easily, for example, output quantities, relative amounts of purchases and sales throughout the agricultural cycle, trading alternatives, road conditions and transportation availability, input sources, credit availability, grain storage facilities and conditions, and market access. These few pieces of information would not be a burden for the production researcher and would be extremely useful for the marketing researcher, especially in the early stages of his research.

Conclusions

The purpose of this paper has been to put the findings of research on grain marketing in the WASAT into a perspective that allows recommendations for the direction of future research. Five major conclusions have been drawn.

1. The diversity of marketing channels, infrastructure, geographic and climatic characteristics of each country militates against a countrywide approach. In the past, studies of one or two regions inside a country have erroneously drawn national conclusions, which have led to policies that are ill-adapted to the perceived problems. Future studies should take a systems approach, identifying the major forces in the marketing system and investigating each, both on their own and for their part in the entire food system. Several levels of investigation are implied: geographical differences in produced and marketed quantities and intertemporal patterns of purchases and sales; roads and transportation networks; storage facilities; economic groups and trader organizations; and government participation in production and marketing activities. The geographical areas have systems of their own that are linked to the systems in neighboring regions and to the national systems. Once the overall picture is understood, more intensive

12. This is not to be misconstrued as meaning that research for its own sake is useless. It is an efficiency issue. In a region where funds and personnel are limited, the best use of such resources is to do research that addresses most directly and completely the concerted priorities of the population. Also, a considerable amount of narrower-in-scope research on aspects of the grain marketing system in the region has already been conducted.

research can concentrate on the most important aspects and specific key regions.

2. Collaboration between production and marketing researchers is essential. Each can contribute valuable information to the other's work. The marketing researcher can provide information about input markets and food marketing problems that may be constraints to adoption of new techniques or seed varieties. The production researcher can offer the marketing researcher needed information about general characteristics of an area and about specific habits of farmers already studied. While this collaboration already exists on a very informal basis in the field, a more formal effort is needed.
3. Government policies have too often aggravated the very problems they sought to alleviate. In part this can be attributed to ill-designed policy, founded in a lack of understanding of the dynamics of the marketing system and the variety of arrangements that exist. It may also be the result of conflicting policy goals. For each country the goals must be reexamined and a realistic (both economically and politically) program designed.
4. The economic literature has been criticized for its relatively narrow perspective, specifically for concentrating on proving or disproving competitiveness, and its reliance on price data. The nature of marketing activities requires an understanding of both the economic (industrial organization) and anthropologic relationships that are part of the marketing system, thus demanding the use of techniques from both disciplines. Omission of one or the other leads to an incomplete explanation of the dynamics of the market and the links between participants.
5. Lastly, while some useful generalizations can be made about the grain marketing systems of the countries of the WASAT, we suggest that enough effort has been devoted to these generalities during the last 5 years. On a regional level, the problems are well defined and the solution formulae well discussed. While offering a framework, general solutions do not deal with the specific, political, climatic, socioeconomic and infrastructure characteristics of each country. It is in these specifics that the key to well adapted policies lies.

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Sorghum Marketing in India

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India produces around 11.8 million metric tons (1977/78 average) of sorghum per annum, which is about 17% of the total world production of sorghum. India's total area of 16.2 million hectares under sorghum (1977/78 average) is about 31 % of the total world area under sorghum. Thus India can be considered a major sorghum producer in the world; however, its sorghum yields are about half the world average. Within the SAT region, India grows 34% of the total sorghum production. Sorghum forms the staple food of a large number of people in the semi-arid regions of India, and it provides 6% of the total caloric intake per person per day (FAO 1977).

Sorghum straw provides a major share of cattle feed in India. Thus both sorghum grains and fodder contribute to the Indian farmers' income, and efforts to improve the production of sorghum in India must take into consideration this dual purpose and utilization of food and fodder of traditional sorghum in Indian agriculture.

Area and Production

Sorghum contributes about 16% of the area under total cereals in India (Table 1), but it contributes only 8% of the total cereal production. Thus sorghum yields are only about half of total cereal yields in India.

Maharashtra, Andhra Pradesh, Madhya Pradesh, and Karnataka are the major producers of sorghum in India. These four states together contribute about 85% of the area under sorghum (Table 2). While Maharashtra has more or less continuously expanded its area and production of sorghum during the past 20 years, the states of Andhra Pradesh and Madhya Pradesh, which until early 1970 followed the same trend, have since reduced both their absolute area and production of sorghum. In Karnataka. dramatic decreases in area under sorghum were observed over the past 10 years, but these were nearly made up by spectacular yield increases so that production in this state declined only marginally.

Among the less important sorghum-producing states the long-run decline in area and production of sorghum appears to continue, except for Tamil Nadu and Gujarat for which the figures for 1975-78 indicate a sudden increase in production.

Generally, the picture is that of a long-run trend towards specialization of certain states in sorghum production. However, the advances over the last decade, of high-yielding varieties (HYVs) particularly suited and adapted to some regions, have led to partial and possibly temporary reversals of such trends. It must be anticipated in the long run, that with increasing commercialization of Indian agriculture, the past trend of regional specialization with interregional trade will continue to locate cropping patterns containing sorghum in all those areas that have a comparative advantage for such systems, i.e., primarily the rainfed areas of Maharashtra, Andhra Pradesh, Madhya Pradesh, and Karnataka.[2]

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1. In 1973, Maharashtra had 7% of its sorghum area under HYV, and in 1978 this figure increased to 27%.

2. Regions with a comparative advantage are not necessarily those having the absolutely highest yields; the comparative advantage for a particular crop exists where and when the demand price minus the cost of production gives, relative to other crops, the comparatively highest return.

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru. A.P., India. Patancheru, A.P. India: ICRISAT.

Table 1. All India area ('000 ha) under various careals and their relative ahara in the total cereals area.

Crops	1954/57	1958/61	1968/71	1972/75	1975/78
Rice	31 520	33 706	37 413	37 621	39 329
	(36.2)	(37.0)	(37.1)	(37.6)	(38.2)
Sorghum	17 021	18 026	18 237	16 139	16 045
	(19.6)	(198)	(18.1)	(16.1)	(15.9)
Pearl millet	11 318	11 197	12 486	12 345	11 119
	(13.0)	(12.3)	(12.4)	(12.3)	(10.8)
Maize	3 734	4 338	5810	5 905	5910
	(4.3)	(4.8)	(5.8)	(5.9)	(5.7)
Finger millet	2 294	2 524	2 497	2384	2 592
	(2.6)	(2.8)	(2.5)	(2.4)	(2.5)
Small millets	5313	5 087	4 754	4.432	4 697
	(6.1)	(5.6)	(4.7)	(4.4)	(4.6)
Wheat	12 383	12 974	16 941	18 685	20 859
	(14.3)	(14.2)	(16.8)	(18.7)	(20.3)
Barley	3 450	3 298	2 692	2 661	2 345
	(4.0)	(3.6)	(2.7)	(2.7)	(2.3)
Total cereals	87 036	91 183	100 831	100 174	102 899
	(100)	(100)	(100)	(100)	(100)

Figures in parentheses are percentages.
Source: Government of India, All India Estimates of Area. Yield and Production (various issues)

Market Channels

Sorghum is primarily grown for home consumption in India. Estimates from various studies indicate that from 1972 to 1977 in the major producing areas, about 10-15% of sorghum on average was sold in the market. Market arrivals varied from state to state (Table 3). In Uttar Pradesh, Gujarat, and Rajasthan more than 15% arrived in the market, while for Tamil Nadu, Andhra Pradesh, and Karnataka this was less than 10%. For Maharashtra, unfortunately figures are not available. Looking at the data on market arrivals over time at the all-India level, it is found that after a low in 1974, market arrivals increased not only for sorghum but also for wheat and especially rice. This may be attributed not only to higher production during those years but also to price policies which made market access and interregional trade in food grains increasingly attractive, by the provision of market places as well as by the removal of food zoning and other trade barriers. As has been shown elsewhere (von Oppen 1978), this increasing commercialization leads to increasing specialization of crop production accompanied by a growth in aggregate productivity. In view of the fact that these policies continued, it can be expected that market arrivals at present of sorghum are between 15 and 20% of the all-India level. To better understand the market channels of sorghum and other ICRISAT crops, several studies were conducted by ICRISAT's Economics Program, some results of which are reported below.

Market Surplus and Market Access for Different Farm Sizes

A detailed study of 20 villages was conducted in Mahbubnagar district to study the effect of market access on market surplus and aggregate productivity.

In these villages, farmers' marketable surplus on average is 28% of the total sorghum production for the three landholding classes (Table 4). The market surplus increases with landholding size. It varies from 5% for the small landholding class to 40% for the large landholding class. Table 5 also classifies the data on the basis of distance to the market, and the influence of the distance on the market surplus. On an average for all landholding classes, the market surplus is the highest with

Table 2. Area, production, and yield[a] of sorghum in selected states of India, over time.

States	1954/57			1958/61			1968/71			1972/75			1975/78		
	Area	Prodn	Yield	Area	Prodn	Yield	Area	Prodn	Yield	Area	Prodn	Yield	Area	Prodn	Yield
Punjab and Haryana	267	41	156	296	54	182	220	48	222	183	52	274	176	34	179
	(1.6)	(5)		(1.6)	(6)		(1.2)	(.5)		(11)	(6)		(11)	(3)	
Uttar Pradesh	928	537	578	906	570	629	759	456	601	717	470	655	690	491	714
	(5.4)	(6.9)		(5.0)	(6.2)		(4.2)	(4.9)		(4.4)	(5.3)		(4.3)	(4.6)	
Rajasthan	1 041	308	295	1 073	318	296	1 097	395	360	971	337	349	.758	276	360
	(6.1)	(3.9)		(5.9)	(3.5)		(6.0)	(4.3)		(6.0)	(3.8)		(4.7)	(2.6)	
Gujarat	1 467	362	247	1 362	303	222	1 314	400	304	970	321	333	1 056	562	533
	(8.6)	(4.7)		(7.5)	(3.3)		(7.2)	(4.3)		(6.0)	(3.6)		(6.6)	(5.3)	
Madhya Pradesh	1 908	992	520	1964	1 291	657	2 437	1 538	631	2 122	1 598	751	1 930	1 355	702
	(11.2)	(12.8)		(10.9)	(14.1)		(13.4)	(16.7)		(132)	(18.1)		(12.0)	(12.8)	
Maharashtra	5 586	2 784	498	5 882	3313	563	6 054	2 784	460	5718	2 577	439	6410	4 422	688
	(32.8)	(35.9)		(32.6)	(36.2)		(33.2)	(30.2)		(35.4)	(29.2)		(39.9)	(41.7)	
Andhra Pradesh	2 494	1 172	470	2 559	1 405	549	2 657	1 213	456	2 709	1 363	507	2 248	1 165	520
	(14.6)	(15.1)		(14.2)	(15.4)		(14.6)	(13.2)		(168)	(15.4)		(14.0)	(11.0)	
Karnataka	2 613	1 049	402	2 801	1091	389	2 939	1 820	619	2 037	1 578	765	1 913	1 535	797
	(15.3)	(13.5)		(15.5)	(11.9)		(161)	(19.8)		(12.6)	(17.9)		(12.0)	(14.5)	
Tamil Nadu	744	518	697	759	581	766	715	530	741	665	504	760	808	742	918
	(4.4)	(6.7)		(4.2)	(6.3)		(3.9)	(5.7)		(4.1)	(5.7)		(5.0)	(7.0)	
All India	17 021	7 751	455	18 026	9 142	507	18 237	9 209	504	16 139	8 826	545	16 045	10615	661
	(100)	(100)		(100)	(100)		(100)	(100)		(100)	(100)		(100)	(100)	

a. Area in '000 ha; production in 000 tonnes; yield in kg/ha

Figures in parentheses indicate percentages.

Source: Government of India, All India Estimates of Area. Yield and Production (various issues).

Table 3. Estimated average arrivals' of sorghum, wheat, and rice from village into wholesale assembling markets as a percentage of production in selected States of India, over time.

State/Year	Sorghum	Wheat	Rice
Andhra Pradesh	8.0		32.8
Gujarat	23.4	34.1	48.2
Karnataka	7.6	14.1	16.0
Madhya Pradesh	13.7	22.0	18.8
Maharashtra		33.5	7.2
Rajasthan	16.3	20.5	13.3
Tamil Nadu	9.0		44.4
Uttar Pradesh	29.4	20.2	23.0
All India	11.5	28.1	24.3
1972/73	14.3	31.2	23.6
1973/74	10.8	23.4	22.4
1974/75	8.8	23.9	22.0
1975/76	11.2	30.5	26.2
1976/77	12.6	31.7	27.0

a. Unweighted averages of the years 1972/73 to 1976/77.
Source: Government of India. Bulletin of Food Statistics. 1979. p. 17.

36% in villages with the nearest market distance (within 15 km) and the lowest with 18% in distant villages (over 25 km from the market).

While small farms have only negligible quantities of sorghum as a marketable surplus at all locations, large farms respond strongly to the increasing market distance with a decreasing marketable surplus of sorghum. Out of the total sorghum produced, 72% is retained on the farm; 51% is used for home consumption (for all categories of landholding class). 17% for kind wage payment and 4% for seeds. While kind payment and retention for seed are constant, regardless of the market distance, the home consumption of sorghum increases, especially in large farms with increasing distance to the nearest market. In other words, for large farmers in the vicinity of a market, sorghum must be considered as a commercial crop.

Market Flows of Sorghum Through Different Channels

In a marketing study of ICRISAT crops, 29 markets were randomly selected in the semi-arid tropical areas of India. For sorghum, markets in Maharashtra and Andhra Pradesh were mainly considered. Estimates of quantities passing through different channels were made based on information collected from traders and farmers in these markets. Figure 1 gives the estimates of flows of sorghum through different channels in 1974/75. About 22% of sorghum is sold in primary wholesale markets and 78% is retained on the farm. From the primary wholesale markets, 7% goes to the local retailer, 10% to secondary wholesale markets and 5% to terminal markets. Again from secondary markets, about 5% goes to retailers and the remaining 5% to terminal markets. Of the 78% retained on the farm, 50% is used for home consumption, 24% for kind payment of wages and 4% is retained for seeds.

Producer's Share in Consumers' Rupee

A detailed investigation into the prices and market margins in three markets in Andhra Pradesh shows that here producers receive about 85% of the consumers' rupee (Table 5). A study further shows that the producer's share in the consumers' rupee decreases as one looks at crops like pigeonpea, chickpea and groundnut because for these products the amount of services required for transformation of the product into a consumable commodity increases. Thus the relatively high share which producers receive of the consumers' rupee is explained not only by a relatively efficient market channel but also by the fact that sorghum does not undergo any physical transformation while in the market channel. Consumers buy the grain as such and do the grinding themselves with the help of local small-scale mills.

Interregional Trade

A large proportion of sorghum is traded within the same district and between districts within the same state. Interstate trade of sorghum over long distances is also observed (Fig. 2), e.g., Maharashtra, Gujarat, and Karnataka import considerable quantities from other states. Sorghum does not flow to the eastern region of India. Its trade is mainly concentrated within the SAT areas of India where it is the staple food. The interregional trade of sorghum is less than that of pigeonpea and chickpea.

Table 4. Production and percentage of market surplus of sorghum by farmers in different landholding classes and with different market access.

Villages	Land holding classa	(A) Production + wage in kind received (Q)	In % of A						% of wage in kind received to production
			Payment in kind	Retained for seed	Retained for house consumption	Retained for future sales	Marketed	Market surplus	
Near	S	145.0	90	2 1	868	-	2 1	2.1	36.3
	M	290 8	21.1	26	55.4	1.4	19.5	20.9	1.6
	L	6570	17.0	26	30.5	12.2	377	499	-
	All	10938	17.1	2.5	44.6	7.7	28.1	35.8	4.1
Middle	S	1457	9.9	1.5	78.3	-	10.3	10.3	326
	M	238 3	19.4	3.3	60.3	2.1	149	17.0	1.6
	L	383 0	19.7	3.4	44.8	3.1	290	326	-
	All	767.0	17.8	3.0	560	22	21.0	23.2	5.4
Far	S	67.3	14.8	1.9	82.2	-	1.1	1.1	20.3
	M	126.1	185	3.3	70.9	-	7.3	7.3	5.7
	L	2540	18.5	3.1	51.6	3.9	229	268	-
	All	447 4	17.9	3.0	61.6	22	153	17.5	4.3
All	S	358 6	10.5	1.8	825	-	52	5.2	31.5
	M	655.1	20.0	3.0	602	1.4	15.4	168	2.4
	L	1294 0	182	29	38.8	7.9	32.2	40.1	-
	All	2307.7	17.5	28	51.6	4.8	233	28.1	4.6

a. S = small; M = medium; L = large: All = all categories
Q = Quintal (100 kg).

Table 5. Average estimate of marketing margins (rupees per quintal) In three markets[a] for five selected crops, 1975-76.

Item	Crops				
	Sorghum	Pearl millet	Pigeonpea	Chickpea	Groundnut
Wholesale traders' level					
Gross margins	14.83	13.23	17.59	17.71	11.36
	(8.77)[b]	(8.03)	(6.87)	(7.10)	(3.72)
Net margins	7.85	6.47	6.76	6.96	6.09
	(4.64)	(3.93)	(2.64)	(2.79)	(199)
Millers' level					
Gross margins			2256	20.43	40.82
			(8.81)	(8.19)	(13.35)
Net margins			11.54	11.55	16.81
			(4.51)	(4.63)	(5.50)
Retailers' level					
Gross margins	7.08	6.18	12.27	10.92	23.50
	(4.19)	(3.75)	(4.79)	(4.38)	(7.69)
Net margins	(4.85)	3.95	7.67	6.61	10.52
	(2.87)	(2.40)	(3.00)	(2.65)	(3.44)
Producers' net price	144.58	142.66	200.13	196.84	226.09
	(85.49)[c]	(86.63)[c]	(78.16)[c]	(78.92)[c]	(73.97)[c]
Consumers' price	169.11	164.67	256.04	249.41	305.66
	(100)	(100)	(100)	(100)	(100)

a. Warangal, Khammam, Tandur.
b. Figures in parentheses are percentages.
c. Producer's share in consumers' rupee.

Price Correlations in Sorghum Markets

The correlation of prices reported from different markets provides a measure of pricing efficiency of these markets. Price correlations vary between pairs of markets in different regions. Table 6 shows the price correlation coefficients among three Andhra Pradesh markets and 28 other selected markets for different products. For sorghum, the correlation coefficients are quite low in comparison with other crops. This could be explained partly with the high variability in the quality of sorghum; average prices, as they are being reported, do not generally refer to the quality of the product. In addition, however, sorghum markets cannot be expected to be highly integrated (as compared with pulses) because of the fact that sorghum trade generally involves much shorter distances than does the trade of pulses (Fig. 2).

Prices Over Space and Time

Price Index of Sorghum Over the Last 15 Years

Sorghum prices have kept in line with the prices for other cereals over the last 15 years, but from 1970 onwards they have increased at a faster rate than wheat and all cereals (Fig. 3). One reason for this recent price rise could be the decline in per capita net availability of coarse cereals, particularly from 1970 onwards. In comparison, the per capita net availability of wheat increased over time, while availability of total cereals remained more or less constant. According to Bapna (1976) "... the aggregate coarse cereal price increased at the rate of 10.5% per annum between 1951 and 1974, while that of wheat and rice increased by 8.4% per annum. The price of coarse cereals during recent years has reached and even surpassed the levels of wheat and rice prices."

Table 6. Correlation coefficients of weekly market prices of selected crops among three selected markets and between each of these and 28 other markets in 1974–75.

Markets	Sorghum			Pearl millet			Pigeonpea			Groundnut			Average[a]
	WGL	KMM	TDR	WGL	KMM	TDR	WGL	KMM	TDR	WGL	KMM	TDR	
Warangal (WGL)	1.00	0.30*	0.40*	1.00	0.93**	0.91**	1.00**	0.96**	0.85**	1.00	0.62**	0.59**	0.47
Khammam (KMM)		1.00	0.88**		1.00	0.90**		1.00	0.94**		1.00	0.72**	0.56
Tandur (TDR)		1.00	0.38*			1.00			1.00			1.00	0.58
Average[b]	0.35*	0.58**		0.56**	0.75**	0.59**	0.74**	0.71**	0.79**	0.25**	0.18	0.56**	

** Indicates significance level at 1%.
* Indicates significance level at 5%.
a. Average across four crops of average price correlation coefficients with 28 other markets.
b. Average of price correlation coefficients between selected and 28 other markets.

Seasonal Price Variation of Sorghum

A study of monthly prices for the years 1970-76 shows that seasonal price variation has a peak in September and a low in the months of February and March. The increase from the lowest to the highest is about 16% in 6 months. Thus the price increase is about 2.6%/month. Interestingly, the market arrivals of sorghum are 33% of the total annual arrivals (average of 1970-76) in January -March and only 18% in July-September (Fig. 4).

Regional Price Variation

Mapping of sorghum prices, by district in four states, shows some interesting regional patterns. During 1957-64 there is not much price variation in sorghum between the districts in the four states, although prices for sorghum in northern Karnataka tend to be the highest, while those in central Madhya Pradesh are the lowest (Fig. 5). However, from 1965 to 1973, sorghum prices in Karnataka attained considerably higher levels than Madhya Pradesh, Andhra Pradesh, and Tamil Nadu (Fig. 6). Restrictions in interregional trade as well as other food policies are responsible for this differentiation of sorghum prices. After the gradual lifting of these restrictions from 1977 onward, the original picture of relatively minor price variation for sorghum across Indian districts is likely to have reestablished itself.

Elasticities

In India, producers and consumers of sorghum respond to changes in prices. This is measured in the form of elasticities, i.e., the percent change in quantities supplied or demanded given a 1% change in price or income.

Demand Elasticities

There are no estimates of the elasticities of demand for sorghum per se; however, since sorghum represents the largest share in the group of "other cereals" (which together with rice and wheat constitute all cereals in India), the elasticities measured by Radhakrishna and Murty (1980) for this group of products reflect largely the case of sorghum (Table 7).

The estimates show revealing differences between urban and rural consumers, especially in

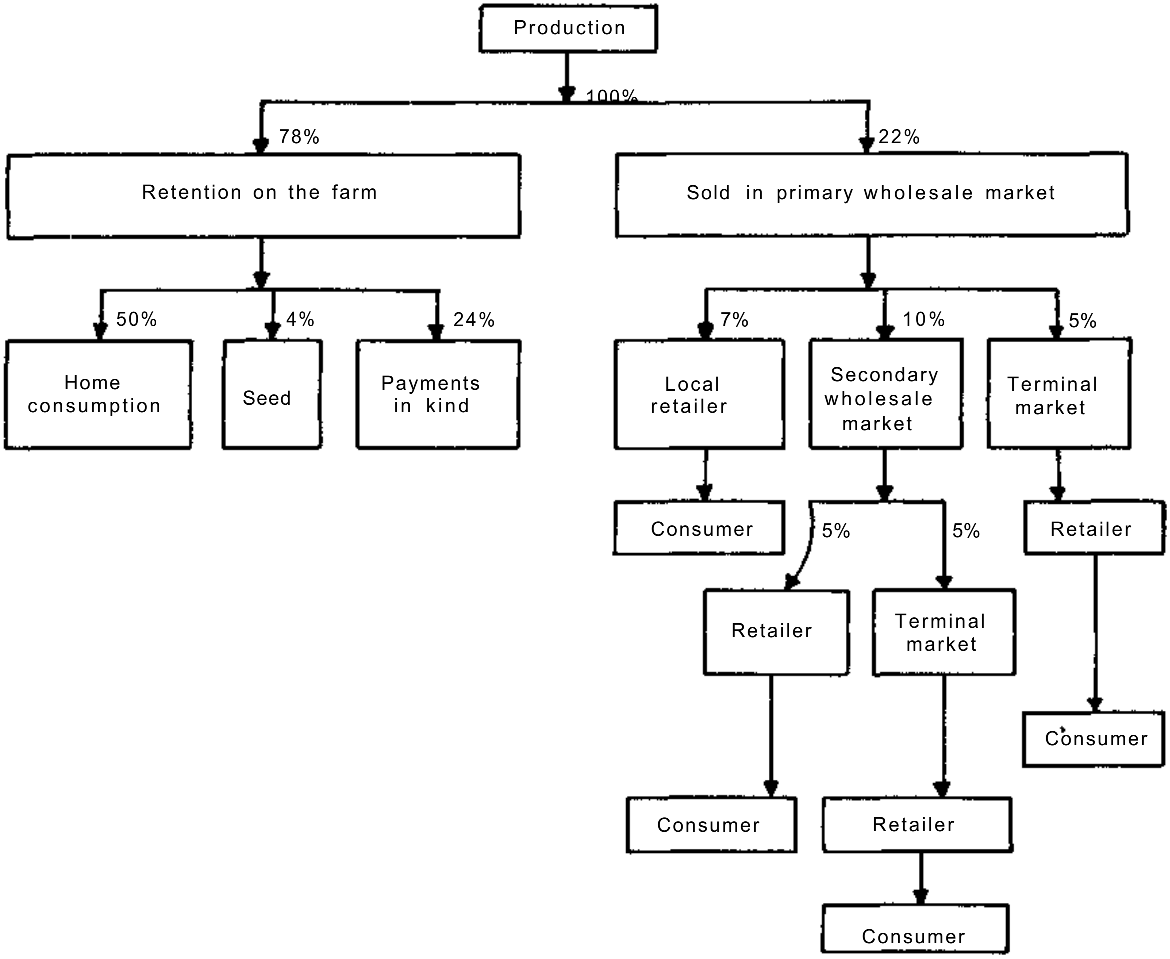

Figure 1. Estimates of flows of sorghum through different market channels. 1974/75.

Table 7. Demand elasticities of sorghum In India.

Income Group	Income elasticities		Price elasticity	
	Rural	Urban	Rural	Urban
I	.881	1.041	-1.541	-3.442
II	.557	.871	-1.030	-2.058
III	.511	.962	- .443	-1.187
IV	.186	.363	- .104	- .289
V	.172	-.450	- .078	.228

Source: Radhakrishna and Murty (1980).

the higher income groups. Generally, with increasing income, consumption of sorghum increases with rural and urban consumers; the elasticity is highest in the lowest income group (I) and it decreases with higher income groups; in the highest income group (V) of urban population consumption even falls with rising income. As prices rise, demand falls in all but the highest income group; in the case of urban consumers this tendency is about twice as strong as with rural consumers. The highest income group of rural consumers shows a nearly zero response to sorghum prices and the urban highest income group even has a positive sorghum price elasticity, i.e., if prices rise this group's demand of sorghum increases.

Supply Elasticities

The supply elasticities of sorghum available at present originate from a personal communication by Hans Binswanger of the Employment and

Name of state	Production (1000 metric ton)	Estimated market arrivals as 7. of production
Andhra Pradesh	1571	8
Madhya Pradesh	1869	18
Maharashtra	3622	NA
Rajasthan	306	31
Gujarat	320	16
Karnataka	1815	5
Uttar Pradesh	397	12

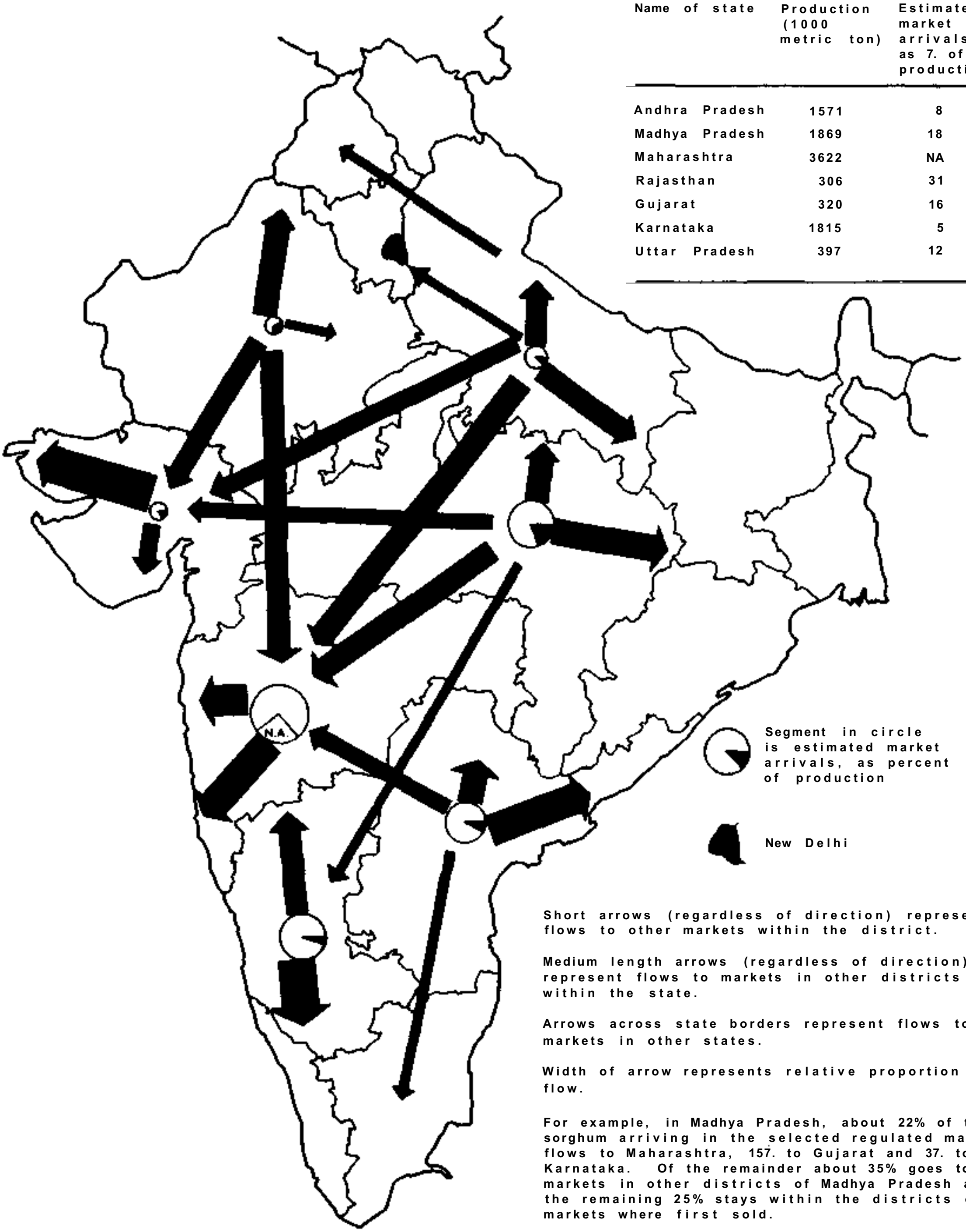

Figure 2. Production of sorghum, market arrivals as percent of production, and total flows (as percent of market arrivals) from selected food grain markets in selected states of India. 1974/75.

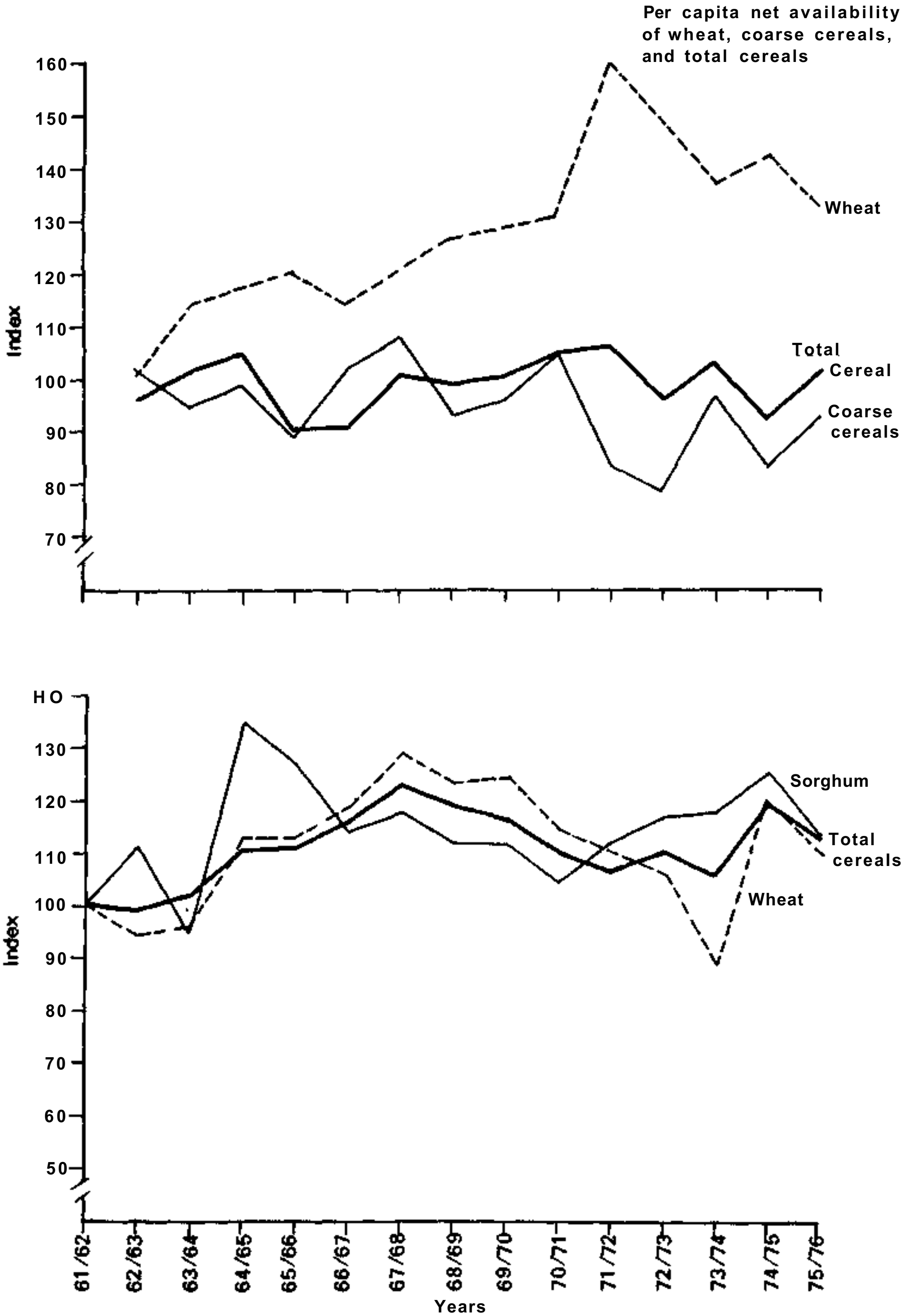

Figure 3. Indices of real prices and per capita availability of sorghum (coarse cereals), wheat, and total cereals (base 1961/62 = 100).

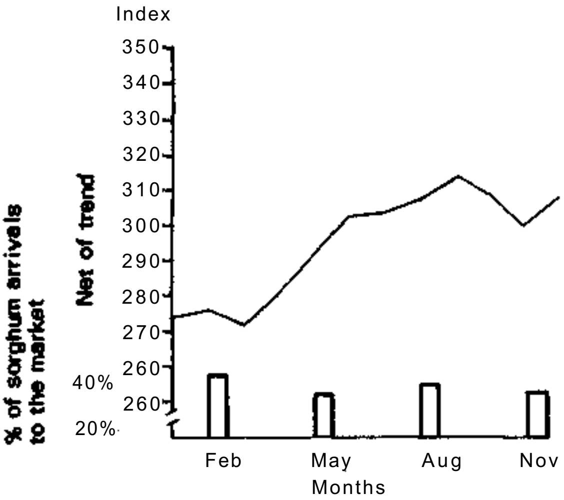

Figure 4. Average monthly detrended index prices of sorghum in India (1970-76) and percentage of sorghum arrivals to the market (1970-76).

Rural Development Department of the World Bank, Washington, D. C. 20433, U.S.A. His research indicates that Indian sorghum producers respond rather strongly to sorghum prices with elasticities ranging from 0.2 to 0.8, depending upon which method of estimation is used. Thus, even though the marketed portion of sorghum produced in India may be low, farmers appear to be well aware of sorghum prices and actually respond quite strongly to its changes.

Quality of Sorghum Grain as a Determinant of Price

On any given market day, prices of sorghum may vary within a range of sometimes 15% or more around the average price. The price differences are caused by differences in the quality mix of market arrivals. Some qualities *are* positively and others are negatively related to price. Using multiple regression analysis, the variation in price due to quality can be estimated (von Oppen and Rao 1982). Not only evident qualities but also cryptic qualities are found to have a statistically significant influence on price. Among the evident qualities, red color and molded grain negatively influence price; also hundred-seed-weight positively affects price. Among the cryptic qualities, dry volume and protein content positively influence price and the absence of swelling capacity negatively influences price.

Sorghum Fodder Markets

Sorghum fodder is an important source of animal feed in India. Most of the straw is used for on-farm consumption. However, excess quantities are sold in urban fodder markets. For a better understanding of the functioning of such urban fodder markets, these were studied in the city of Hyderabad.

The fodder markets in Hyderabad are not organized or regulated as are the major grain markets in Hyderabad and elsewhere in India. The transactions are not officially recorded. The market yard is a piece of land belonging to a group of persons who also act as commission agents. Fodder is brought to these markets in cartloads from neighboring villages from a distance of 15-70 km, and sometimes in trucks from distances of 300 km or more.

The mode of transaction is quite simple. Fodder is sold on a per cart basis; one cart contains about 100 bundles. The seller displays a few bundles of his straw for the buyer to inspect. Other than in grain markets, there are no auctions in the fodder market and the commission agent (the owner of the market place) proposes a price to the satisfaction of the buyer and the seller.

Seasonal Variation in Prices

The seasonal variation in sorghum fodder prices is depicted in Figure 7. Sorghum stalk is divided into five varieties that are commonly found in the market (besides HYV sorghum). For all the varieties of sorghum, fodder prices are high during the months of May, June, and July. During the postharvest months of November, December, and January, prices are very low. The graph also shows that the variation in fodder prices was higher in 1977 than in 1978. The reason is that from January 1978 fodder supplies began to be drawn from a wider radius, i.e., as far as Kurnool and Cuddapah districts, which are 300 km away from Hyderabad.

Spatial Variation of Sorghum Straw Prices

As already mentioned, sorghum straw is brought from neighboring villages. If price differences per

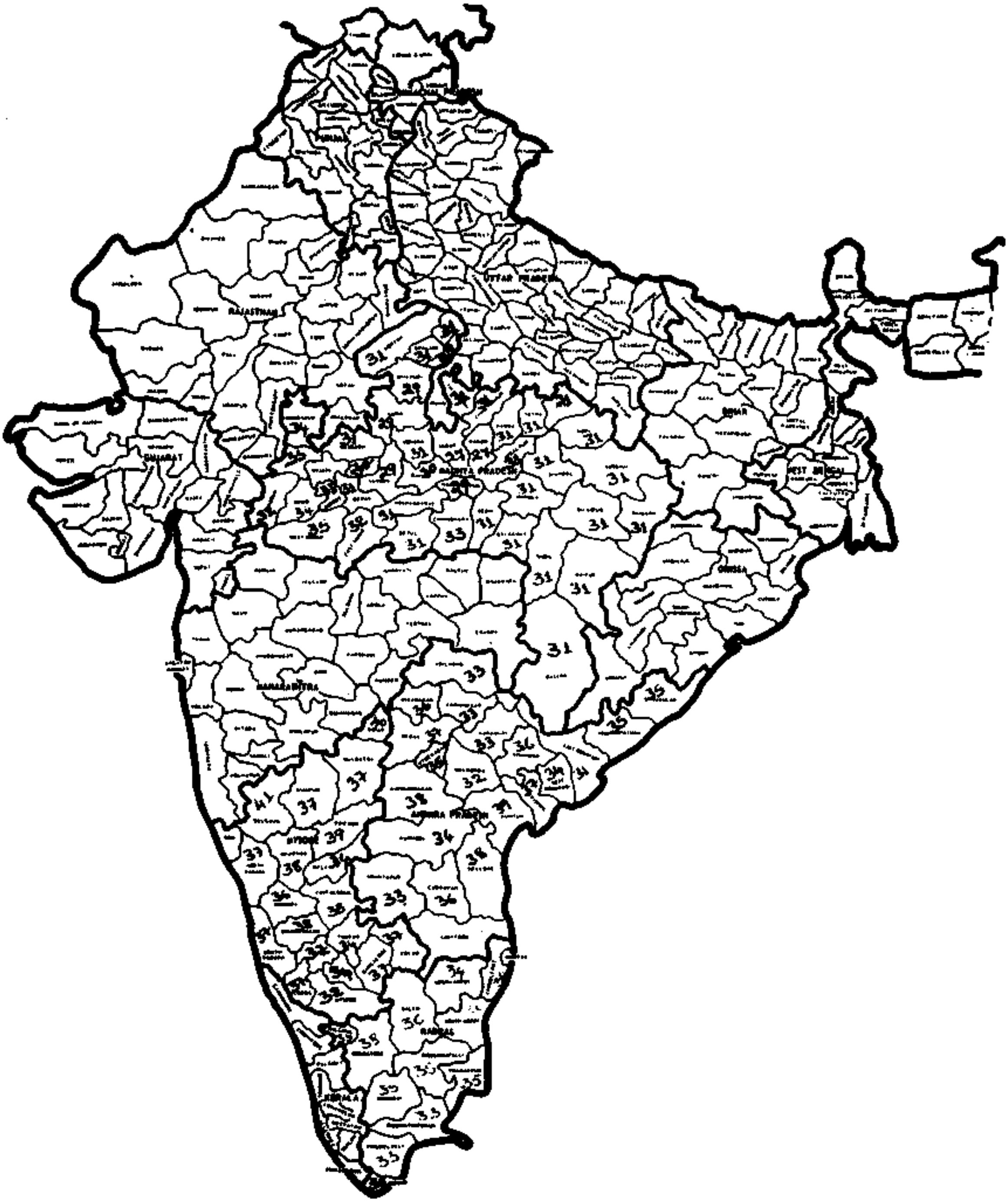

Figure 5. Average sorghum prices in selected states (average price by district) over 8 years from 1956/57 to 1963/64 in rupees per quintal.

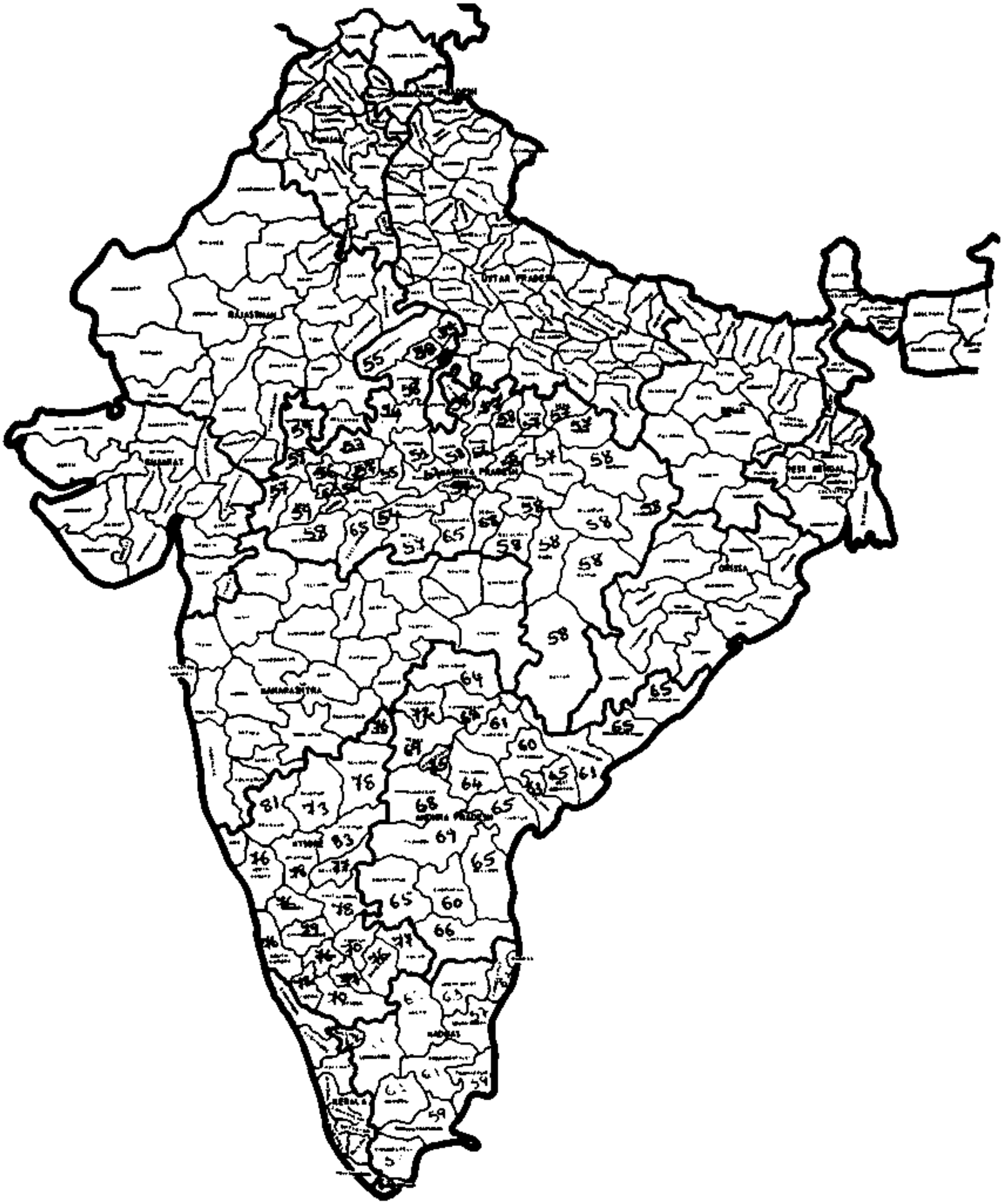

Figure 6. Average sorghum prices in selected states (average price by district) over 8 years from 1964/65 to 1972/73 in rupees per quintal.

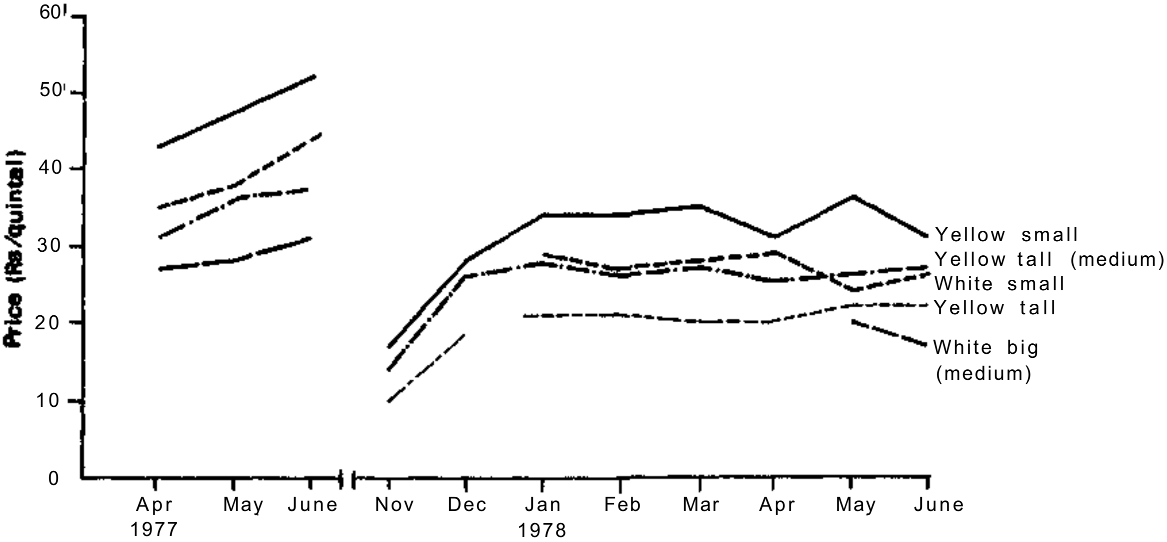

Figure 7. Seasonal variation in sorghum fodder prices.

cartload (i.e., one hundred bundles) between the village and the Hyderabad market are expressed as a function of distance in miles for different types of sorghum straw jointly and relative to yellow tall straw (Table 8), a distance coefficient of 0.52 is found; i.e., for every 10 miles the margin increased by Rs. 5.20 per cartload of sorghum straw. In other words, as distance increases, the village price decreases in line with the transportation cost of about 0.52 Rs/mile.

Variation in Price Due to Quality of Sorghum Straw

Yellow sorghum straw fetches a higher price per unit of weight than white sorghum straw (the farmers consider yellow sorghum straw to be more nutritious). Among yellow sorghum straw, the straw of shorter varieties fetches a higher price than the tall varieties. One reason could be that tall varieties cannot be fed directly to the animals because the stalks are long and hard. It has to be cut by a machine into small pieces before it can be consumed. The HYV sorghum stalk price is about 30% lower than the price of local sorghum stalk in Hyderabad in November (it was about 40% lower in Dokur village for 1977/78). Because of this price discount, only negligible quantities of HYV sorghum stalk arrived in the market. According to commission agents, buyers are willing to buy HW sorghum stalk provided they are green. After drying, HYV stalks are considered to lose their fodder value and the animals are reluctant to eat HYV stalks.

Value of Grain and Straw of Sorghum

The present study enables us to estimate the relative values of grain and fodder from traditional and high-yielding varieties. Given the yield of sorghum grain and the yield of stalks from a particular plot, the total value of output can be computed by multiplying with the appropriate market prices.

For this purpose, averaged grain and fodder yields for the years 1976, 1977 and 1978 for black and red soils were obtained from farming systems experiments at ICRISAT Center for local and HYV sorghum. The fodder and grain prices for sorghum for the month of December 1977 were used in Hyderabad and Kandi markets. (The Kandi weekly market is located about 55 km away from Hyderabad.) The results of the computation are presented in Table 9 and show that the value of fodder for HYV sorghum is only about 25% of the total value of output (main product and by-product) whereas for the local variety it is 55%. Consequently, the value of grain is 75% for HYV sorghum and only 45% for the local variety. However, the total value of output for HYV sorghum is only about 200-300 rupees/ha higher than that of traditional varieties. Even if the comparison is based on the lower prices for local yellow sorghum and HYV sorghum grown during the *kharif* season, the advantage in favor of HYV

Table 8. Regression coefficients (t-values In brackets) explaining the margin[a] of sorghum straw as a function of qualities relative to a reference quality[b] and distance to the urban fodder market.

Distance in miles	W. Small	W. Medium	Y. Small	Y. Medium	Intercept	R^2
0.52 (8.1)	-5.45 (-2.9)	-4.08 (-1.8)	-14.32 (-7.7)	-8.83 (-4.4)	19.79	0.41

W = White sorghum; Y = Yellow sorghum.
a. Margin is defined as market price minus village price in Rs/cartload.
b. Reference quality: "yellow tall."

Table 9. Comparison of fodder and grain values between local and high-yielding varieties of sorghum.

Product	Item	Sorghum variety	
		Local	HYV[a]
Grain	Yield (100 kg/ha)	12	31
	Price (Rs/100 kg):		
	Osmangunj	126	84
	Kandi	107	77
	Value (Rs/ha):		
	Osmangunj	1512 (45)	2604 (73)
	Kandi	1284 (45)	2387 (76)
Fodder	Yield (100 kg/ha)	66	48
	Price (Rs/100 kg):		
	Osmangunj	28	20
	Kandi	24	16
	Value (Rs/ha):		
	Osmangunj	1848 (55)	960 (27)
	Kandi	1584 (55)	768 (24)
Total (grain and fodder)	Value (Rs/ha):		
	Osmangunj	3360 (100)	3564 (100)
	Kandi	2868 (100)	3155 (100)

a. Figures in parentheses indicate percent to total value of production.

sorghum amounts to not more than 500 to 600 Rs/ha. Considering the additional cost of production of HYV sorghum, this relatively small difference in total value of HYV sorghum may explain the limited adoption of high-yielding varieties in many parts of India.

In view of the general importance of sorghum as a major source of grain and as fodder for cattle, the value of fodder should be considered in breeding new varieties.

If a hybrid sorghum with high quality straw could be developed without a serious decrease in grain yields, the resulting attractiveness to the farmer would probably greatly speed adoption of such a type.

Conclusion

India is a major sorghum producer in the world, although its yields are only about half that of the world average. Yield increases through new varieties are possible; however, the adoption of new varieties may be constrained because of the fodder value of traditional varieties and because of grain qualities preferred in the traditional varieties.

The importance of sorghum straw as fodder in the Indian economy emphasizes the need in this country to either breed new dual purpose varieties, i.e., those with both good grain qualities and good fodder qualities, or to offer the farmer alternative technologies which would permit him to plant special grain types of sorghum and special fodder types of sorghum (or any other suitable fodder crop) at the same time; improved technologies of fodder conservation such as silage might have to be included in this technology package.

In the end, the returns from new dual purpose varieties or from specialized grain and fodder production would have to exceed those from the local dual purpose varieties of traditional sorghum.

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Some Important Socioeconomic Issues Concerning Sorghum in India

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Sorghum is one of the four major cereal crops of the world. In 1979 (FAO 1979), it was grown over an area of 50.879 million ha and the production was 67.268 million metric tonnes. Seventy-five per cent of the world area but only about 40% of production came from Asia and Africa, where the grain is mostly used as human food. The yield was 0.69 t/ha in Africa and 0.88 t/ha in Asia. In North America and other countries, where the grain is used mostly as animal feed and in industries, the yield level was 3.4 t/ha.

Sorghum is raised as a forage and silage crop in some countries, while in some other countries, industrial uses of the grain are on the increase. Results indicate that sorghum is about as good a feed grain as maize for pigs, cattle, sheep, and poultry (Anon. 1972). It is shown to be even better than barley and oats. Stover (stubble) is used for feeding animals in many countries where it is grown for food grain. Sorghum is mainly a crop of semi-arid regions although it thrives well in subhumid conditions. It is grown in tropical, subtropical and temperate regions of the world. Response to controlled irrigation is substantial and it can, therefore, be grown with advantage as an irrigated crop in limited water supply situations. Yields as high as 4 t/ha have been obtained under irrigation in the UAR (Anon. 1972). Still better results are obtained in some parts of India. Biologically, sorghum is an efficient crop plant and it needs to be exploited to the fullest extent possible for the good of mankind.

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Indian Situation

India produced about 84 million tonnes of cereals in 1971. Rice production was 38.74 million tonnes and that of millets and wheat was 24.40 million tonnes and 20.86 million tonnes, respectively. In 1978/79, the level was 119.2 million tonnes comprising 53.8 million tonnes of rice, 34.98 million tonnes of wheat and 31.12 million tonnes of millets (Anon. 1980). The position of millets has now moved down to third rank giving the second place to wheat. Rice, however, has retained its prime position and is likely to maintain the same in future.

The aggregate consumer demand for food and supply possibilities in 1985 and 2000 AD as projected by the National Commission on Agriculture (NCA) (1976a) are given in Table 1.

Sorghum requirements have not been worked out separately. Production possibilities, however, indicate that the level of 20.04 million tonnes could be reached by 2000 AD even by using the technology available now (NCA 1976b).

Sorghum is grown in the semi-arid and subhumid regions of the country. The area, production, and productivity levels in different years are given in Table 2.

There is an increasing trend in production as also in productivity. The area, however, is varying between 16 and 18 million ha. The projection made by the NCA indicates that even in 2000 AD the area would continue to remain at 17 million ha. Yield levels, however, would require to be raised from 0.48 t/ha in the 1969-72 period to 1.2 t/ha in 2000 AD. To achieve this level of production, various measures like the use of hybrids, fertilizers, pest control, etc., would have to be adopted

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum. 2-7 Nov 81, Patancheru. A.P.. India. Patancheru. A.P. India: ICRISAT.

Table 1. Aggregate consumer demand and supply possibilities (in million tonnes) of cereals in 1985 and 2000.

	1971	1985 Demand		Possible supplies	2000 Demand		Possible supplies
Rice	38.74	Low	52.40	61.00	Low	68.76	80.00
		High	56.60		High	73.98	
Wheat	20.85	Low	29.60	41.00	Low	41.04	50.00
		High	33.39		High	45.89	
Other cereals	24.40	Low	30.93	40.00	Low	37.79	65.00
		High	30.73		High	38.53	
Total cereals	83.71	Low	85.00	120.72	Low	147.59	195.00
		High	112.93		High	157.00	

Source: NCA 1976. Final report Part III: Demand and supply: Chapters 10 and 11: pages 15 and 87, respectively.

Table 2. Area (In million ha), production (in million tonnes), and yield (t/ha) of sorghum grain in different years in India.

Year	Area	Area under irrigation	Percent area under irrigation	Production	Yield
1950/51	15.571	0.463	3.0	5.495	0.35
1955/56	17.362	0.625	3.6	6.726	0.39
1960/61	18.412	0.655	3.6	9.814	0.53
1965/66	17.679	0.714	4.0	7.581	0.43
1973/74	16.716	0.677	4.0	9.097	0.54
1977/78	16.318	0.805	5.0	12.064	0.74
1978/79	16.125	0.719	4.5	11.563	0.72

Source: Basic statistics relating to the Indian economy, 1950/51 to 1978/79. Central Statistical Organisation. Department of Statistics, Ministry of Planning, Government of India: Pages 27 and 29, respectively.

in addition to paying required attention to various socioeconomic issues.

General Policy Issues

Wheat and rice are considered to be food grains superior to sorghum and other millets for various reasons. Scope for converting the millet grains into animal products is tremendous, but losses occur in the process of conversion. Possibilities of improving the quality of sorghum grain through breeding and processing for direct use also appear to be considerable. Serious attempts are needed in this regard. There are many policy issues which need attention at various levels.

India is a Millet Country

From the point of view of the agro-climatic conditions, India is a millet country. But, the realization of this fact has not been sufficient. Without irrigation, paddy is grown only in heavy rainfall regions of the country where the rainfall is adequate in terms of magnitude and spread. The analysis carried out by the NCA shows that only about 7-8% of the present paddy area can be hopefully supported with rain water which can be said to be more than adequate for raising the crop successfully. Twenty-five percent of the paddy area is irrigated. The remaining 66% of the area lies in the zones where rainfall is inadequate and, therefore, the yields are low. Only the low-lying areas in these zones can be retained under paddy by diverting water from high-lying areas.

Wheat is another important food crop which has been receiving good attention. This is a crop which is grown in the winter season and, as such, has to depend on moisture stored in the soil, or on irrigation. Suitable conditions prevail only in some parts of the country.

It may be easily seen that the scope for increasing the area under paddy and wheat are very limited. Increase in the productivity level can, no doubt, be brought about by adopting intensive measures. Irrigation becomes the key factor in increasing the production of rice as well as wheat. There is always a limit up to which the water resources can be stretched. Therefore, the matter that needs examination is, whether it is more advantageous to use irrigation water for paddy which requires more water than other crops. Paddy needs three to four times more water than millets. If there is a shortage of cultivated area and excess of water, then the proposition of growing paddy under irrigation can be justified. In areas where water is scarce and the land that needs irrigation is vast, any scheme to grow paddy under irrigation cannot be substantiated on any account. As far as wheat is concerned, there is no reason why cultivation of wheat should not be extended wherever irrigation facilities exist. Wheat is as good as millets from the water use economy point of view. Temperature, however, becomes a limiting factor. On the other hand, maize, sorghum, *ragi,* and many other millets have the inherent capacity to grow and yield well under harsh conditions where rice and wheat may not thrive well.

In some parts of the wheat belt of the country, it has been shown that maize yields are much higher, even in the winter, than wheat. Similarly, sorghum under irrigated conditions do very well even in the summer. Sorghum has been found to yield 15 t/ha of grain in 6 months in the southern parts of the country. The CSH-1 crop sown at the end of January or the beginning of February is ready for harvest by the end of May and the ratoon crop can be harvested in August. Therefore in 6 months, two harvests can be obtained. Sorghum is shown to be better than rice, wheat, and *ragi* in this regard. Detailed studies would further unravel the potentialities of sorghum.

National policy with regard to crop planning requires to be reexamined and reoriented keeping in view the water-use economy and overall production and productivity of various food crops.

Food Procurement Policy

It has been the practice in the country, during the last decade or so, to announce the procurement and support prices for food grains. The procurement price for sorghum was Rs. 740 per tonne in 1976/77 and 1977/78; it was Rs. 750 in 1978/79 and Rs. 950 in 1979/80. This was raised to Rs. 1050 in 1980/81. The prices are similar for coarse paddy, but they are Rs. 1100, 1120, 1150, 1170. and 1300 per tonne for wheat for the corresponding years. Every year, grain is procured to build up a buffer stock. The quantities of food grains procured internally in different years are given in Table 3. This stock is used for distribution through fair price shops in urban as well as rural areas. The stock is also used for meeting the needs of the rural people in the years of scarcity.

Famines and scarcity conditions occur more often in drought-prone areas than in the favorable areas. It is the poor people who need the food grains in such areas—mainly coarse grains. When the stock consists mostly of wheat and rice, it becomes difficult to meet the demand for millets. Superior grains are costly and less sustaining than coarse grains. When there is no other way but to make wheat available in the areas where millets constitute the staple diet, the problem of misuse arises. To get over all these difficulties it seems advisable to procure and stock the coarse food grains also in required quantities.

The notion stated to be prevalent against procurement of coarse grains is with regard to storage quality. It is believed that maize and sorghum grains do not store well and are prone to attack by storage pests. *Ragi* and other small grains, of course, store very well for a long time. It is further argued that there is not much marketable surplus of maize and sorghum grains. It is also common to come across distress sales of these two grains in some years and in some parts of the country. These grains are stored all over the world and shipped through long distances, proving that they are amenable to long-duration storage.

It was estimated by the NCA that about 25 million tonnes of coarse grains would be required by 2000 AD to meet the needs of the animal industry. Unless production of millets is increased by adopting suitable measures it will be difficult to step up the production of animal products. Since

Table 3. Internal procurement of various food grains (in million tonnes) in India.

Year	Wheat	Rice	Other grains including sorghum
1968	2.373	3.373	1.059
1969	2.417	3.581	0.383
1970	3.183	3.043	0.488
1971	5.058	3.462	0.307
1972	5.024	2.550	0.091
1973	4.531	3.462	0.431
1974	1.885	3.482	0.228
1975	4.098	5042	0.423
1976	6.618	.5.999	0.232
1977	5.171	4.642	0.147

Source: Bulletin of food statistics, 1978. Directorate of Economics and Statistics. Ministry of Agriculture and Irrigation. Government of India. 37 pp.

there has been a worldwide demand for coarse grains as feed for animals, there would be scope for exporting the surplus production of these grains.

There is need for convincing data to show how and why it is advantageous to increase the production of millets and also to procure and stock the same in large quantities. Research should be intensified in this regard and data made available to policy makers to enable them to take proper decisions and implement them.

Need for Suitable Genotypes for Different Regions

Sorghum is grown in areas where the rainfall is restricted to 4 months in a year, i.e., June to September. It is only in some parts of Maharashtra. Andhra Pradesh, and Karnataka that some rainfall occurs in October also. One of the most critical factors in the growing of sorghum is that of sowing the crop on time. Earlier sowings are preferred to avoid shoot fly damage and the risk of drought during the maturity period. Varieties grown in different areas vary very much in duration. Traditional varieties are such that they usually mature after the cessation of rains. Attempts are now being made to introduce hybrids or high-yielding varieties of shorter duration that are suitable for varying rainfall situations. Introduction of hybrids and varieties which mature earlier than the traditional varieties has brought in the problems of earhead pests and diseases since the grain formation and maturity take place when humidity is high and the rains are expected. The problem of drying the grain has also come to the fore because of cloudy weather at that time. It is for these reasons that the produce is brought to the market when still wet. Therefore, distress sales are reported to take place in some markets. Public sector organizations also avoid procurement to escape from the problems of storage.

It would be advantageous in many ways to develop and recommend hybrids or high-yielding varieties which fit into the rainfall rhythm of a place rather than to introduce only early maturing types irrespective of the duration of rainfall. Gardner (1972) has stated that "Maximum grain production can be attained by breeding for a more limited set of environments rather than breeding for very broad adaptability. This also has the advantage of protection against disasters due to diseases or insects which often attack a specific genotype." It has been universally realized that maximum economic yields can be expected only when the growth pattern of the crop is well adapted to environmental conditions.

Research approaches need to be clearly defined with regard to breeding of varieties for different agro-climatic regions. If short-duration varieties are introduced, measures will also have to be suggested to tackle the problems that go with them. A proper approach should be formulated and implemented at research as well as at development levels in this regard.

Need for increased Attention to *Rabi Jowar*

In Andhra Pradesh, Maharashtra, and Karnataka, *rabi jowar* is valued most. The prices of *rabi jowar* are usually higher than those for other kinds. The problems of raising *rabi jowar* are on the increase because of considerable soil erosion taking place. The soils are getting less and less retentive because of the washing away of the top soil and they are becoming more drought prone. The problems concerning the development and release of suitable varieties or hybrids, soil and water conservation, soil fertility management, etc.. are the most important ones. Certain pests and diseases are also assuming a serious magnitude. Research programs need to be intensified urgently to tackle the problems of *rabi jowar.* It would be possible to do so only by strengthening the organizations at the state level.

Consolidation of Land Holdings

It is possible to stabilize as well as to increase the yields of sorghum only when the structure of land holdings in the country is improved. Due to various historical reasons, holdings have been divided, subdivided, and fragmented to such an extent that it is practically impossible to adopt any soil and water conservation measure based on contours. Contour cultivation is impossible when the holdings are narrow strips which run up and down the slope. With such a land holding structure, it is difficult to lay out the land for better soil and water conservation or to construct farm ponds for harvesting and storing water to be used for supplementary irrigation at critical stages. None of the recommendations pertaining to soil and water conservation except contour bunding is being practiced. Contour bunding is also taken up by invoking the provisions under land improvement acts enacted by different states, but not by individual farmers. It is shown that contour bunding is not effective enough unless other cultural and manurial practices are adopted. It has also been observed that for various reasons, structures are not being maintained properly. The only solution to this problem appears to be to consolidate the holdings in such a way that it would facilitate adoption of the recommended soil and water conservation measures. Unless these measures are adopted to the maximum extent possible, it is not going to be easy to increase agricultural production in the rainfed areas beyond a certain limit. If nothing is done in this regard as early as possible, the chances of retaining the existing top soil, which is the capital of the dry land farmer, will further diminish. It is already late enough and if the available chance is also lost, it would be as good as losing eternally all hopes of development of the semi-arid tracts. It is therefore necessary to formulate a policy with regard to the consolidation of holdings and implement it in the shortest possible time.

Availability of Power and Implements

The problem closely connected with land development is that of power availability for farming in rainfed areas. The land is required to be leveled and laid out in a suitable *manner* to get full benefit from the water received through rain. The objective has to be to store as much rain water as possible underground, in ponds and in the soil profile. It is also necessary to carry out all the cultural operations on time. The time available for these operations is very short. If the few available chances are missed, the year is as good as lost. There may be only one chance in some years. Sowing also has to be completed in a very short period. This cannot be done unless sufficient power is available either in the form of animals or machines. Similarly, there will have to be suitable implements for carrying out these operations efficiently.

It may be of interest to note that it is mostly in the semi-arid and subhumid tracts in India that there are good and varying types of implements for carrying out cultural operations. One would come across different kinds of plows, harrows, drills, interculturing implements, land-leveling implements, etc., showing that the farmers in these tracts have realized the importance of good implements. What is needed in the future, however, is to build up an organization for making available better machines and implements for land development as well as for carrying on other field operations. Sowing is a critical operation and the time available for it is very limited. It is for this operation that maximum attention is required to be paid. More research and development efforts are needed in this regard.

Policy decisions have to be taken at various levels keeping in view the need and scope for building an infrastructure not only for carrying out research on machines, implements and tools, but also for making available, on a hire basis or on a custom services basis, the machines and implements required for leveling land and for carrying out various agricultural operations so that these operations may be completed in time.

In summary, it is necessary to stress the need for a reexamination of the policies pursued up till now insofar as sorghum is concerned and to modify and reorient them in such a way that they would encourage production of millets and sorghum thus improving the overall productivity as well as production of food and animal products in the country.

Seed Production and Supply

Every variety of a crop is endowed with a certain inherent production potentiality. The limit can be reached by adopting recommended production technology, provided the seed is of the right variety and of the right quality. It has, therefore, been appropriately said that it is the seed that sets the limit of production. The importance of the seed in increasing agricultural production has been recognized since long ago.

Historical

New crops and varieties have been recommended for general cultivation for many years. Whenever new crops or new varieties were introduced or developed as a result of research, attempts were made to produce and distribute seeds of such varieties through the channels available and to the extent possible under the prevailing circumstances.

It has been shown that the use of improved seed is one of the cheapest methods of increasing production which mainly needed organizational efforts. Considerable emphasis has been laid on this program as a part of the overall national plan for agricultural development during the planning era starting from 1950. A number of seed farms were started for the production of foundation seeds and a number of farmers were enrolled and registered as seed growers for production and supply of certified seeds, with the main objective of making every taluk in the country self-sufficient.

With the release of new hybrids and high-yielding varieties in the country in the 1960s, the program assumed an altogether different dimension and conception. The first seed testing laboratory was established in 1961. The National Seeds Corporation (NSC) was set up in 1963. The Seed Act was passed in 1966 and the Seed Review Team (SRT) gave its report in 1968 in which it made recommendations keeping in view the need for a strong seed industry in the country. In the initial stages, the seed industry made tremendous progress—considered as of a kind unparalleled in the world—in a short period. Douglas (1972) analyzed the situation as it existed in the beginning of the 1970s and made important and relevant suggestions for the development of the seed industry in the country with special reference to sorghum. The position was analyzed in depth by the NCA and the findings and recommendations can be found in its interim report (1972) as well as in the final report (1976c).

Intensive efforts to popularize sorghum hybrids began in 1966/67. Progress achieved can be seen from Table 4. The area covered in 1979 was about 15%. Coverage has been better in Maharashtra and Karnataka but only in the *kharif* season. The available hybrids and varieties have been found to be suitable to conditions prevailing in the months of summer and *kharif* seasons. The optimum period for sowing has been observed to be from February to June. Attempts made so far to develop suitable hybrids and varieties for the *rabi* season have just resulted in the release of a few varieties suited to some areas only and they are yet to become popular.

Present Position

The seed industry has been built up to a certain extent during the last 15 years. The question now is whether the existing infrastructure is sufficient to produce and supply the needed quantities of seed of the appropriate quality. The sorghum seed requirements in 1985 and 2000 AD as projected by the NCA are given in Table 5. It must be said that as far as production of seed is concerned, there is no dearth of farmers who are capable of producing the needed quantity of seed. A good number of farmers have been trained, while many more can be trained in a short period. It has been successfully shown that farmers in India, although illiterate, have the capacity to absorb technology concerning seed production and to deliver any quantity of certified seed under an agreement with an agency. The problem, however, is in organizing a large number of farmers in different parts of the country and in motivating them to

Table 4. Area (in million ha) under sorghum hybrids.

Year	Area	Year	Area
1966/67	0.19	1973/74	1.10
1967/68	0.60	1974/75	1.31
1968/69	0.70	1975/76	2.19
1969/70	0.56	1976/77	2.37
1970/71	0.80	1977/78	3.10
1971/72	0.69	1978/79	3.10
1972/73	0.87	1979/80	3.00

Source: Unpublished data from the Planning Commission, Government of India, New Delhi.

Table 5. Projected area (in million ha) and production (in million tonnes) of sorghum wed in the different states. Data in parentheses are in ha and tonnes.

	1985				2000			
	Hybrids		Varieties		Hybrids		Varieties	
	Area	Prodn	Area	Prodn	Area	Prodn.	Area	Prodn.
Total area under hybrids or improved varieties	3.88	—	3.88	—	11.34	—	5.66	—
Breeder seed (A)	(2.6)	(2.6)	(5.99)	(3.1)	(2.5)	(3.6)	(2.8)	(2.1)
Foundation seed (B)	(316.0)	(312.8)	(382.6)	(198.1)	(443.0)	(633.5)	(267.6)	(200.7)
Certified Seed (C)	(39191.9)	(38800.0)	(24871.7)	(12933.3)	(79300.7)	(113400.0)	(25155.6)	(18886.7)
Total seed (A+B+C)	(39510 5)	(39115.4)	(25260.2)	(13135.3)	(79746.2)	(114037.1)	(25426.0)	(19069.5)

Source: Final Report of NCA, Part X: Chapter 47: 43-46.

produce seed of good quality. The seed produced by them has to be taken over, processed, and marketed.

As estimated by the NSC, the total seed-processing capacity for all seeds put together is about 300 000 tonnes only. State corporations, cooperative organizations and private agencies deal in seed. These agencies enter into a contract with seed growers on mutually agreed terms. The seed thus procured is processed and marketed by the seed agencies. Government organizations, however, have withdrawn from direct seed business in many states.

ICAR institutes and agricultural universities have the responsibility for the production and supply of the required quantity of breeders' seed. The NSC continues to act as the national agency for foundation seed and also acts as a coordinator of the seed program in the country. A National Seed Program has been launched to strengthen the facilities of breeders' seed and foundation seed agencies in the country. All the agricultural universities are being involved in the program, with these universities being responsible for the production of breeders' seed and foundation seed for supply to the NSC.

Various organizations for handling the seed business will have to be consistently and systematically built up in order to meet the increasing needs of the country. This will be possible only if appropriate policies are formulated and implemented at the national as well as the state levels.

Policy with Regard to Release of Varieties

The general rule has been to release the varieties first and then gradually introduce hybrids. But, in India, a new technology based on CSH-1 hybrid came into being in the middle of the 1960s. Later, "Swarna", a high-yielding variety was released. So far, eight hybrids and seven varieties of sorghum have been released through the All India Coordinated Research Project (Rao 1980). A few hybrids have also been released by private firms. None of the varieties has become as popular as the hybrids. One of the important issues that requires careful consideration is with regard to the policy of releasing hybrids and varieties.

The seed business has been largely concentrated in hybrids since there is a certainty of sale, as well as money in it. A better margin of profit can be expected in the case of hybrid seeds, but not with varieties. The hybrid seed has to be purchased every year; the farmer cannot retain his own seed. This gives a certain amount of assurance as far as the sale of hybrid seeds is concerned. In the case of varieties, since the farmer can retain his own seed, there cannot be any such certainty. Unless there is an assurance of an attractive turnover, it will be difficult to attract entrepreneurs in the industry. Even the government-sponsored cooperatives or corporations cannot survive when the turnover is not assured at an optimum level. If the farmer is tempted to keep his own seed when varieties are released suddenly, then the business in hybrids is likely to slump down and it may take years to build up the trade again when hybrids that are better than the varieties are developed and released.

It has been shown that hybrids are better than the varieties in many respects such as yield, quality of produce, tolerance to stress conditions, etc. Hybrids also provide increased employment opportunities in the activities connected with seed production, processing, and marketing. Varieties have certain advantages too. Here the farmer can retain his own seed. This is the main advantage and as a result the spread of a variety can be expected to be much faster than that of a hybrid. Another advantage claimed is that the seed cost is low as compared with hybrids. It has also been expressed that timely availability of hybrid seeds cannot be ensured because of problems pertaining to the operation of commercial trade channels. It has not however been realized that the cost of the seed is only a small fraction of the total cost in raising the crop and therefore, what matters is the extra yield one gets by using hybrid seeds over the other types. It is wrong to say that the farmers are unable to pay for the seed. The farmers in India have demonstrated that they would be prepared to spend on seeds if they are assured of timely availability and increased returns. Once the infrastructure is built up, it should not be difficult to make the seed available in the places where they are required and at the right time.

Taking all these factors into consideration there is an urgent need to crystallize thinking about these issues, evolve a policy and implement it scrupulously so that proper incentives could be made available for the development of seed industry.

Extension Effort

As stated earlier, seed is an important input. Awareness has to be brought about in the minds of farmers that it pays to use seed of good quality. Extension efforts in this regard have not been sufficient. Tests on farmers' fields using the certified seed as against any other seed commonly available with farmers, are not many. Such tests will also serve as demonstrations. Sufficient data are required to be built up, analyzed, and presented to the extension workers by researchers, and by extension workers to the farmers. The seed industry is also required to play its own role in this regard. Creation of an awareness regarding the advantage of using quality seed is an important factor in building a strong seed business.

Areas and Seasons for Seed Production

Seed production cannot be expected to be very successful in all areas and in all seasons. In general, dry and irrigated areas and off-seasons are preferable for various reasons. Such areas and seasons should be marked out and appropriate seed production technology formulated and advocated for adoption by farmers. It is only then that the level of productivity of the seed crop would improve and the cost of the seed would come down. The unfavorable areas would ultimately get eliminated. Efficient seed producers in areas which are more favorable will remain in the business.

There is increasing evidence to show that there is an urgent need for carrying out research to demarcate areas and seasons for seed production. The seed agencies including farmers are coming to their own conclusions by a hit and miss method at heavy cost. Such costly exercises can be avoided if research is carried out in this regard and suitable recommendations made for the use of those interested and involved in the seed business, including seed producers. Research efforts in this direction are required to be stepped up immediately.

Problems in General

A number of problems have come to the surface in recent years, which are required to be solved. New problems are likely to arise in future. They will have to be identified in advance if possible, and remedies suggested. The problems relate to quality control, transport bottlenecks, availability of credit, unhealthy competition, forecasting seed requirement, processing, packaging, storage, seed crop insurance, etc. A number of recommendations and suggestions are available in the report of the SRT (1968) and in the interim and final reports of the NCA (1972; 1976c). These should be reviewed and appropriate action taken from time to time.

Use and Supply of Fertilizers

Fertilizers constitute the key input for stepping up agricultural production. They have played an important role in stimulating production all over the world. In India too, a similar impact is evident in recent years. It is of special significance to India in view of the low land: man ratio which is expected to be only 0.15 ha by the end of the century. Fertilizer consumption has increased from 0.34 million tonnes in 1961 /62 to 2.84 million tonnes in 1973/74 (NCA 1976d). Provisionally, fertilizer consumption during 1980/81 is placed by the Government of India (1981) at the level of 5.58 million tonnes.

Potential and Effective Demands

Data on cropwise use of fertilizers is not easily available. Demand studies have been carried out in the country since 1965 when new technology based on high-yielding varieties was introduced. Comprehensive studies in this regard were carried out by the NCA (1976d). Recent studies are those carried out by the National Council of Applied Economic Research (NCAER). Estimates made by the NCAER for 1977/78 and 1986/87 are given in Table 6.

Potential demand indicates technical possibilities and the estimate is based on the recommended rates. Potential demand is therefore the upper limit of fertilizer use for a particular crop. Effective demand on the other hand is based on the rates actually used and probable changes that may occur as a result of changes in the factors of demand. The actual use, however, is always lower due to various reasons. The studies on effective demand aim at knowing the probable use in advance to enable realistic planning for production and supply of fertilizers.

It is seen from the report (NCAER 1979) that the potential demand is about three times the effective demand in case of sorghum although for all crops, the ratio is about two to one. This gives an indication that the effective demand for fertilizer as far as sorghum is concerned is slow in building up. This is reflected in the share of fertilizers for sorghum in the all-India demand for all crops. It is just 1.63% while the gross cropped area under sorghum is about 10% of the total cropped area in the country. The share in potential demand is 315 600 tonnes out of an all-India total of 15.611 million tonnes, i.e., about 2% of the total. Even

Table 6. Projected affective and potential demands (in thousand tonnes) of fertilizers for 1977/78 and 1986/87.

Nutrient	1977/78		1986/87	
	Sorghum	All crops	Sorghum	All crops
Effective demand				
N	40.1	2541.4	75.8	4389.5
P_2O_5	9.0	760.4	19.9	2004.6
K_2O	6.0	367.0	15.3	1400.3
NPK	55.1	3668.8	111.0	7794.4
Potential demand				
N	80 6	4315.6	162.2	8281.2
P_2O_5	42.4	2094.2	84.8	4033.4
K_2O	32.9	1681.9	68.6	3296.4
NPK	155.9	8091.5	315.6	15611.0

Source: NCAER 1979. Pages 42-45 *in* Projection of fertiliser demand.

the share in the total potential demand is low indicating that the recommended dosages also are low as compared with other crops.

Cropwise estimates of effective demand for 1977/78 and 1986/87 have been made by the NCAER. The effective demands for sorghum for 1977/78 and 1986/87 have been estimated to be 55 100 and 111000 tonnes of NPK which is 1.50% and 1.42% of the total demand for the concerned years. The percent share of the all-India demand is 1.56 and 1.72 for N, 1.18 and 1.00 for P and 1.63 and 1.09 for K for 1977/78 and 1986/87, respectively. Potential demand for total NPK for sorghum is estimated to be 155 000 and 315 600 tonnes.

It is but natural to expect such a situation because the area under irrigated sorghum is estimated to be 2.2 million/ha in 1986/87 out of the total projected area under sorghum of about 18.2 million ha, although the area receiving adequate rainfall is indicated as 9.3 million/ha leaving about 7 million ha in low rainfall zones (NCAER 1979).

There are several constraints to using fertilizers in India. The study has brought out that less than half of the farming households in India (45%) actually used fertilizers in the middle of the 1970s. Percentages vary from about 92 in Punjab to 6.5 in Assam. The entire area owned by users was also not fertilized. Only 30% of the areas was fertilized although it was as high as 76 and 72% in Punjab and Kerala, respectively, and as low as 3 to 4% in Assam. The main reason given by the nonusers is nonavailability of irrigation facilities (48%). Another reason is stated to be nonavailability of credit (17.5%). It is however gratifying to note that only 10.8% of the nonusers have stated that they are not aware of fertilizers and another 10% have considered fertilizers to be harmful to soil. The remaining 13.8% have given some other reasons. Another important finding is that the majority of nonusers have been small holders having less than.1 ha (46.3%). 1-2 ha (25.3%), and 2-4 ha (16.4%).

This study has clearly shown that fertilizer consumption is, to a very great extent, limited to irrigated areas and that small holders are not using fertilizers mainly because of the nonavailability of credit. It can be inferred from these conclusions why the use of fertilizers is not popular with sorghum growers. It is because sorghum is mainly a rainfed crop and another probable reason is the nonavailability of credit.

Cost Benefit Ratio

The cost-benefit ratio is an index of the economic feasibility of a proposition. The physical returns and gross financial returns from sorghum as compared with paddy and wheat (FAI 1980), worked out on the basis of fertilizer prices in June 1980, are given in Table 7. The ratio is observed to be less favorable in the case of sorghum. It is only in the case of potash that the gross financial return on every rupee spent on fertilizer is more favorable than in the case of wheat and paddy. There are many other factors which affect fertilizer use levels. The important one is that of risks involved in using fertilizers. The risks involved are greater in the case of sorghum as it is mostly a rainfed crop and it is also prone to a number of diseases and pests, especially when the crop is sown out of season.

The nonavailability of fertilizers and credit ,on time weigh heavily against the use of fertilizers on sorghum. In dry areas, fertilizer distribution centers are fewer and financing institutions are also fewer and weaker. Corrective measures required to be taken are those concerning the timely supply of fertilizers by opening more distribution centers and the easy and timely availability of credit. In addition, technology is required to be improved further to get a better response to fertilizers by bringing about improvement in the time and method of application, and with regard to soil and water conservation measures. Timely availability can be improved greatly by appointing a few farmers as part-time distributors in every village and by stocking fertilizers nearer to the consuming centers. Recommendations have been made in this regard on a number of occasions during the last 20 years. Even then attention paid to these aspects cannot be said to be sufficient.

There is considerable scope for improving fertilizer use efficiency by using appropriate implements to place the fertilizers. Simple implements have been designed and recommended. The implements are not easily available either for purchase or on hire. Making these implements available on a hire basis will go a long way towards encouraging farmers to use these simple devises for obtaining better returns.

Extension Efforts

As projected by the NCAER, only about 2 million

Table 7. Physical and gross financial returns on sorghum on the basis of prices effective from 8 June 1980.

Nutrient	Kg of grain required to buy 1 kg of nutrient			Gross financial returns on every rupee invested on fertilizer		
	Paddy	Wheat	Sorghum	Paddy	Wheat	Sorghum
N	4.58	3.72	5.12	2.62	3.23	1.09
P_2O_5 (as DAP)	5.19	4.21	5.80	1.35	1.66	0.69
K_2O	1.93	1.56	2.15	2.10	3.20	5.34

Source: FAI 1980. Pages 72-74 *in* Annual review of fertiliser consumption and production 1979-80.

ha would be under irrigation in 1986/87. By 1985, as projected by the NCA, irrigated sorghum would be 1.5 million ha (NCA 1976e). It is seen that as much as 9 million ha of sorghum is in adequate rainfall regions and 7 million ha in low rainfall regions (NCAER 1979). In irrigated and adequate rainfall areas, there is no doubt about the advantages of using fertilizers. Even in low rainfall areas, the response to fertilizers has been shown to be enough and economical. What is needed therefore is to intensify the extension efforts to convince the farmers about the advantage of using fertilizers. The quality and number of demonstrations are not adequate enough to give a good coverage in all the tracts.

Supplemental Irrigation

Stabilization of sorghum production is possible by providing supplemental irrigation through various measures. The possibilities have to be explored and utilized. One of the measures is to divert some of the water resources, now being used for raising paddy under irrigation, to low and medium rainfall areas. The need and scope for harvesting and storing rain water, for use during critical periods in adequate rainfall areas as well as in low rainfall areas, are eminent. Technologically, it has been shown that the scope for increasing as well as stabilizing the yields are tremendous in all the rainfed zones in general, and the low rainfall zones in particular, by adopting the farm pond technique. Problems in the construction of storage ponds and in lifting and using the water stored are still to be resolved. As stated earlier, the holdings are not of an appropriate size and shape to facilitate laying of plots for harvesting and storing rain water. The contrivances needed for lifting and applying water are not easily available.

The investments needed on the construction of ponds and on contrivances for lifting water are quite heavy for dryland farmers to bear. Credit facilities and also technical help needed in this regard are not easily available. As a result, soil and water conservation measures are restricted to contour bunding only. Follow-up action for popularizing agronomic practices that go with contour bunding is not vigorous. As a result, the use of fertilizers in dry-farming areas is minimal although farmers are convinced of the advantages of improving the fertility status of soils through judicious use of manures and fertilizers. Unless these handicaps are remedied, it will be difficult to achieve the level of production required to be achieved in the 1980s and by the end of the century.

Use of Chemicals for Plant Protection

In recent years, chemicals are becoming increasingly important as an input for raising agricultural production in India. The plant protection methods used before the year 1950 consisted mainly of cultural and mechanical methods, although chemicals were used for seed treatment and for controlling certain pests and diseases on some cash crops like vegetables. In 1955/56 the quantity of chemicals used was about 16 g/ha and by 1974/75 it had increased to 180 g/ha as against 10 790 in Japan, 1480 in the USA and 1870 in Europe (NCA 1976f). In 1971 /72 the total quantity of chemicals used in the country for protecting crops against ravages of pests and diseases was just 30 000 tonnes of technical material. It is expected to be 52 000 tonnes in 1980/81 (Government of India 1981). The projections made by NCA (1976f) indicate that by 1985/86, the level should reach 0.14 million tonnes. This shows that the tempo of development is not as it should be. The increase suggested by the NCA is in view of the need for preventing the losses caused to various crops.

Present Position

A number of diseases and pests including weeds are known to be responsible for lowering the grain and fodder yield of sorghum. The insects and disease-causing organisms have been studied in detail in different parts of the world and various control measures have been developed and advocated for adoption by farmers. The measures as recommended are being adopted in India only when the pests or diseases assume serious proportions.

Sorghum has never received much attention insofar as crop protection is concerned, except in the case of smuts for which seed treatment with sulphur has been the most effective method. Seed treatment has become popular in the country since it is a very simple and cheap method to control smut disease. As a result, the severity of this disease is on the decline.

Whenever polyphagus pests like army worms or grasshoppers have infested particular areas in an epidemic form, control measures have been adopted on a community basis under the provisions of pest control acts enacted by various state governments. It was only with the introduction of hybrids in 1964 that the sorghum growers in the country became conscious of the fact that sorghum also needs protective measures. The spectacular yields of hybrids, reported in the beginning, attracted the attention of sorghum growers all over the country and there was a scramble for seed which was sold at Rs. 15-207 kg. The enthusiasm resulted in indiscriminate sowing of the CSH-1 crop, in and out of season, unmindful of the fact that it was susceptible to many pests especially when it was sown in certain parts of the year. Shoot fly was very damaging when the crop was sown between July and October. The crops sown between February and June were comparatively free from pests. Earhead pests and diseases assumed serious dimensions in later years.

An evaluation study of the High Yielding Varieties Program for 1967/68 and 1968/69, carried out by the Project Evaluation Organisation of the Planning Commission, indicated that the loss due to pests and diseases on sorghum hybrid was as much as 11-12% in 1967 and 29-42% in 1968 (NCA 1976f). The severity of some pests was so great in some parts of the country that it has left a permanent scare about pests on hybrids in the minds of growers. Even now, the popular feeling is that sorghum hybrids are very susceptible to pests and diseases, including the *Striga* parasite, and that growing hybrids without an adequate know-how and financial support is a very risky affair. The fact that hybrids grown in the normal season, when the traditional varieties were grown, are as safe is still to be driven home emphatically and convincingly. The seasonal aspect of shoot fly incidence is being increasingly understood and adjustments are being made in sowing dates to the extent possible. Chemical methods are also being adopted under certain circumstances. The earhead pests and diseases, however, are taking a heavy toll in humid areas especially if the rains occur when the crop is in the grain formation and development stage. In certain areas, the *Striga* parasite is becoming serious. Attempts made to control it with chemicals is not proving to be very popular or rewarding.

Constraints in Using Chemicals

It is necessary to state again that the risk bearing capacity of sorghum growers in general, and those in the low rainfall areas in particular, is low. The network of supplies and services organizations is too sparse in the sorghum-growing areas to ensure timely supplies and services. Credit availability is also not adequate and timely. Under the circumstances, it is natural to expect a solution to these problems from the plant breeders in the form of resistant varieties. Agronomists and plant protection specialists can also make their contributions in the way of suitable agronomic practices and other simple methods which would help in keeping these maladies under control at less cost and effort. It is expected that there will be major breakthroughs in the ensuing years in this respect. Even then, there may not be any escape from using chemicals for saving the crop from these ravages.

The main requirement to make sorghum growers plant-protection conscious is to arrange for the timely supply of quality chemicals along with the technical know-how. The package of technical know-how should include not only choice of chemicals and details of time and methods of application, etc., but also the safeguards required in using these chemicals to avoid the hazards of pollution. The organizations entrusted with these responsibilities have been weak and also the personnel manning the structure have not been adequately equipped to shoulder the responsibility. The crux of the problem, therefore, centers around inadequate organizations. The other shortcomings have been the absence of an appropriate quality control mechanism and inadequate arrangements in the supply and upkeep of equipment needed for using the chemicals.

In summary, it can be said that it is necessary to strengthen the extension, development, and the supplies and services organizations to better tackle the problems of pests, diseases, and the *Striga* parasite in the future.

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Research Systems

L Busch and W. B. Lacy*

Why study research? Does not studying research systems detract from the process of doing research itself? And. what is to be gained through the study of research systems? Such questions are worthy of consideration, for clearly the study of agricultural research systems is not an established field of inquiry.

Without belaboring these questions, let us attempt to answer them. First, it should be clear to all that agricultural research systems that are poorly organized are simply ineffective. We need to know more about research organization in order to determine what characteristics are likely to promote high quality research. Second, agricultural research emerged during the colonial period in world history and was designed to serve colonial interests (Busch and Sachs 1981). Many of the institutional structures, and even tacit assumptions made by scientists during the colonial period have been held over to the present. Are such structures and assumptions valid? Do they promote development or dependence? Third, agricultural research may inadvertently lead to undesirable social and economic change. This suggests that a better understanding of the operation of research systems may help us resolve the apparent antithesis between efficiency and equity.

In this paper we begin by examining briefly the historical development of agricultural research. Then we examine the current structure of the research system. The next section deals with the process of research decision making. Finally, we deal with the products of research and their policy implications.

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An Historical Overview

Time and space do not permit a detailed analysis of the historical development of agricultural research systems. However, a brief sketch of the models used in agricultural research will help to focus upon the key issues to be confronted during the eighties. As noted previously, agricultural research in less developed countries emerged not from the demands of farmers but, in large part, in response to the demands of the colonial powers for a wide range of tropical products. As Brockway (1979) and Spitz (1975) have noted, the transfer of plant material across the continents dates back to at least the 1500s.

Until very recently, the model employed in virtually all agricultural research was what we call the *diffusion* model (Fig. 1). In the diffusion model the researcher acted upon a research territory receiving certain signals in return that indicated increased yields and/or return upon investment. These research results were then diffused to farmers for use in their fields. Often, these research results were developed in the temperate, industrialized countries and passed on directly to farmers without close examination. This was particularly true in the case of foodstuffs, as most research actually carried out in the tropics concerned the so-called "export" crops. In general, the assumption was that research results obtained at experiment stations would be reproducible on farmers' fields if the farmers followed the proper instructions. As a result, farmers were often exhorted, and occasionally forced (e.g.. Comet 1965), to employ the allegedly improved methods.

The diffusion model remained the dominant model for agricultural research and extension until well into the middle of the 20th century. It was frequently unsuccessful. What diffusion studies failed to note was that the farmer's goal was not so much to increase productivity as to obtain a

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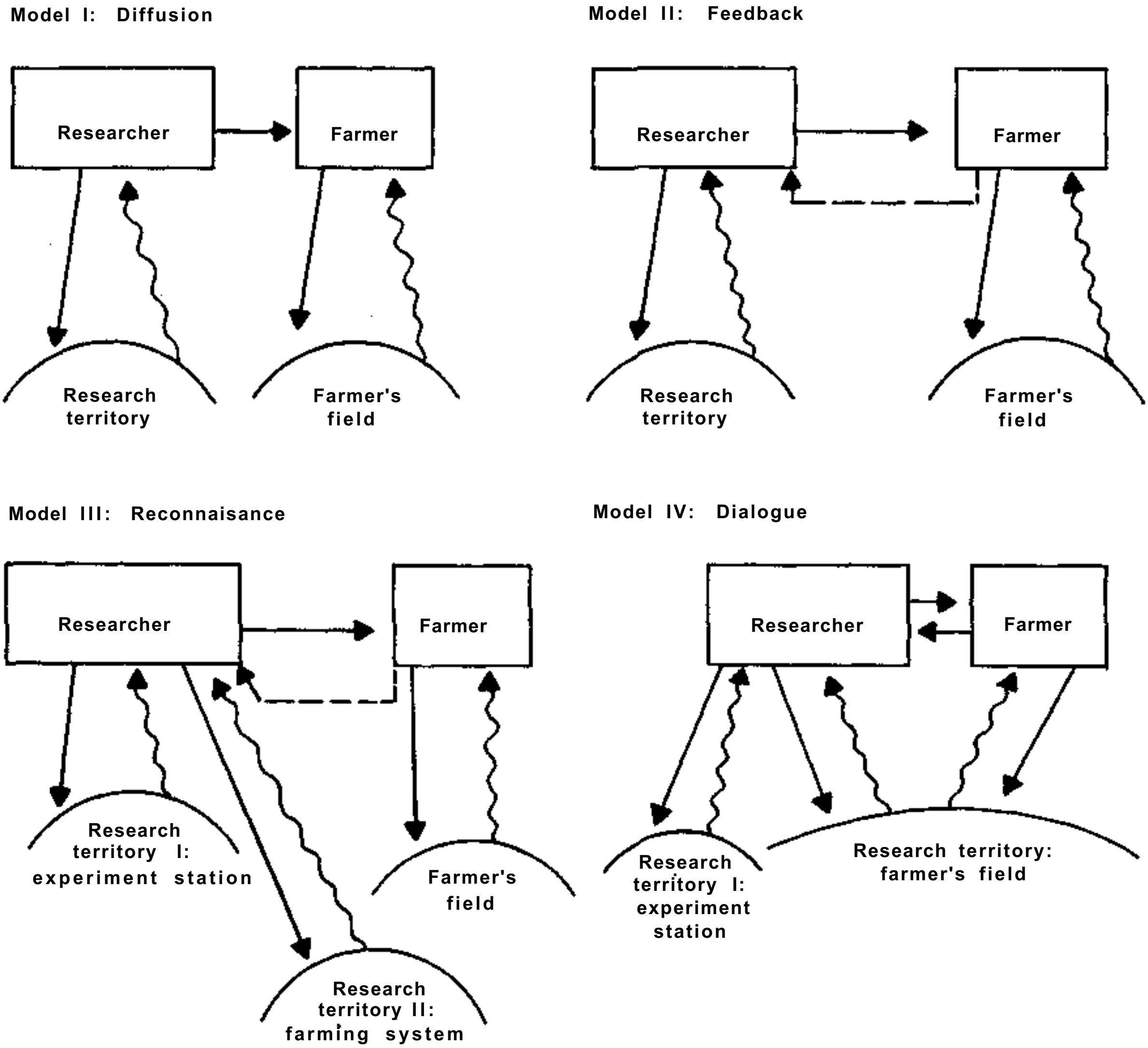

Figure 1. Models of agricultural research.

livelihood. As the late Andrew Pearse (1980, p. 20) has put it:

> "For the typical rural head of family, the central problem of livelihood is one of how to produce or obtain by exchange or purchase sufficient food for all the year round to maintain the members of the family in a condition of 'normal' good health."

As a result, a great number of factors other than economic and technical ones enter into innovation decisions (Mbithi 1977). Moreover, studies of diffusion processes frequently pointed out that people most likely to adopt agricultural innovations were those who were most cosmopolitan, best educated, wealthiest, and had greatest access to credit (Rogers and Shoemaker 1971). In short, people most likely to adopt agricultural innovations were those most like the researchers.

By the mid-1950s a model was developed which we have labeled the *feedback* model. Research was still conducted largely on experiment stations and rarely on farmers' fields. However, after information was supplied to the farmer on the new innovations that research had produced, the farmer was asked if he or she —and more likely he than she—had adopted the new innovation and if not, why not. The result was a substantial improvement in the communications process though it nevertheless remained a one-way process. The basic underlying assumptions still remained: It was assumed that the researcher had the right answers to the right questions. The farmer was only consulted to see whether or not the message delivered by the researcher (or his agent) had been received.

More recently, with the development of so-called farming systems research, a new model has developed. We have labeled this new model the *reconnaissance* model. In this model, research continues to be conducted in the original way on experiment stations. However, a new research territory has been added, that of the so-called farming system. This clearly represents a vast improvement over the older feedback model. However, it still contains certain serious drawbacks. As is illustrated in Figure 1, the research territory called a farming system is not the farmer's field itself. Of course, both farming systems research and the actual practice of farming by peasants tend to take place in precisely the same physical location. However, the social location of the researcher and the farmer remain distinct. The tendency in farming systems studies has frequently been to approach the farmer and perhaps his or her family with an enormous battery of questions. Then, responses of large numbers of farmers have been collated and statistically analyzed in accordance with the researchers' theoretical perspective. The questions however, have remained those of the researcher and not of the farmer. Moreover, often researchers have presumed that the farmers' responses reflected the actual state of affairs and that the farmer was free to openly answer the questions asked by the researcher. In general, the farmer was rarely asked what questions he or she saw as relevant, or what the answers to such questions might be. As a result, while the perspective of the researcher was far closer to that of the farmer than it had been before, there still existed a gap between their understandings of the problems at hand.

Most recently, a fourth model has emerged, that of *dialogue.* Here the researcher interacts with the farmer as an equal, as a partner in the research process. The research territory then becomes the farmer's field itself and the farmer becomes an active participant in the research decision making process itself. To date, this has happened in only a few instances. Moreover, the results have been mixed because often researchers tend to employ elaborate techniques that remain beyond the comprehension of farmers. However, this mode of research appears to hold substantial promise for it puts the researcher, to a far greater degree, into the everyday world of the farmer. We shall have more to say about this model later.

The Current Structure of Research on Sorghum

The development of international agricultural research centers is of recent origin and the development of an institute with specific focus on the semi-arid tropics is an even more recent event. Like most of the other international agricultural research centers (IARC), ICRISAT was organized on the model developed at CIMMYT (Wade 1975. p. 91). However, unlike many of its sister institutions, ICRISAT faces an institutional environment quite different and far less likely to yield the same spectacular kinds of yield increases accomplished with wheat and rice.

Specifically consider the following:

1. Those farmers who are the ultimate target of new sorghum research are substantially poorer than those engaged in the cultivation of wheat or rice. Moreover, most farmers who cultivate sorghum do so under rainfed conditions in relatively poor soil (Kanwar 1980).
2. Markets for sorghum tend to be small and relatively fragmented. They are also susceptible to local or national price policies that discourage production.
3. The very poverty of most sorghum producers in the semi-arid tropics makes it highly unlikely that any capital-intensive technology, based on high levels of inputs will be successfully adopted.
4. Both wheat and rice have long been the subject of agricultural research in western countries. CIMMYT and IRRI could, therefore, draw from an immense body of scientific literature in developing varieties suitable for more tropical conditions. The very fact that sorghum is of substantially less economic importance to the developed countries means that ICRISAT continues to have a smaller backlog of scientific information upon which to draw.
5. Most of the other international centers were established during a period of generally sustained worldwide economic growth. This

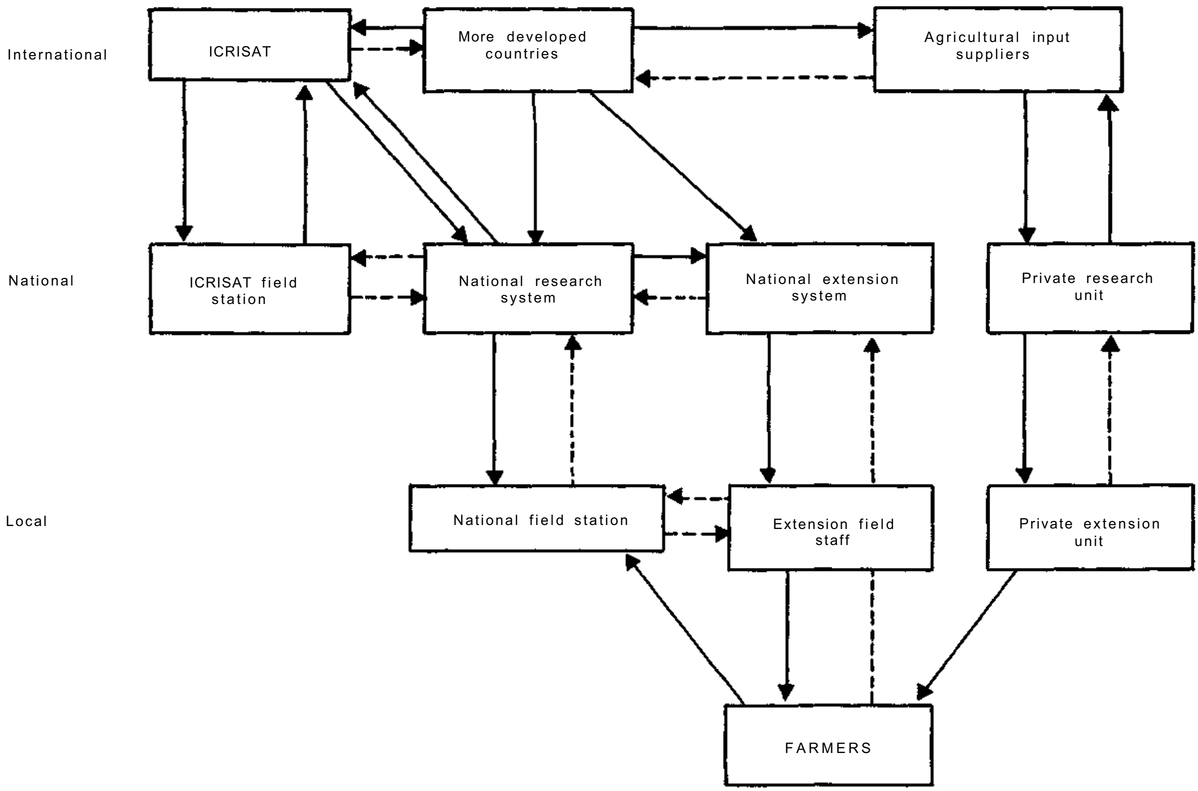

Figure 2. A model of the contemporary structure of sorghum research.

growth made possible the development of substantial numbers of them. However, as we enter into the eighties, the world economy is in a far more precarious condition and further growth of the international centers is highly unlikely over the next decade (Evenson 1978, p. 226).

6. The national research systems with which ICRISAT must interact are both varied in size and effectiveness and often incapable of effectively performing adaptive research.

ICRISAT is located at the top of an increasingly complex and varied system (Fig. 2). It interacts with a variety of national research systems. These interactions are both direct as well as through the various field stations which ICRISAT has established around the world. These national systems range from old established systems with large numbers of well trained scientists to newly established systems with virtually no trained scientists or resources. All, however, suffer from certain serious deficiencies.

First, there is a tendency in most national research systems for money to be spent on commodities that have been researched for the longest time (Evenson 1978, p. 229). Such commodities are nearly always export crops. Second, extension systems tend to be much larger than research sytems despite the fact that there is often little to extend. Third, reward systems for scientists tend to be poorly developed and even counterproductive. Such reward systems may encourage the best scientists to become full-time administrators, may reward seniority over quality, and encourage the publication of relatively esoteric papers in western journals (e.g., Hargrove 1979/80, p. 122). Clearly, such reward systems need to be altered (Chambers 1980), yet virtually no baseline data exist upon which to plan organizational change. Indeed, Moseman's (1970 p. 38) observations of a decade ago are probably still accurate: "In general, agricultural research in developing nations is more personalized than organized, and depends largely upon the initiative, vigor, and level of training of individual research workers."

Pressure to provide employment has left many agricultural research systems with large numbers of trained Ph. D.s and few or no resources. Yet, without access to scientific literature and certain basic research tools, relatively little research will be accomplished in national systems. On the other hand, a lack of resources may be used as an excuse to do nothing at all and is part of a self-fulfilling prophecy that sees research as merely the hallmark of modernity rather than a vehicle for development.

Finally, as Koppel (1979, p. 125) has noted, "it is clear if not always admitted, that relationships between the international agricultural research centers and the national agricultural research systems are often characterized by divergent assumptions about who should and should not be doing what." In the past, researchers could consider their research successful if it resulted in an increase in the yield per hectare of a particular commodity (Bohnet and Reichelt 1972. p. 146). Currently, and in part due to the critics of the Green Revolution, researchers are being asked to take a much wider range of factors into account in assessing both research problems and research products.

The relations between research and extension raise another set of problematics. In many countries, research and extension are organizationally separate institutions. In some cases this may, and undoubtedly does, serve to put one more roadblock in the way of the effective diffusion of even the most sound research results. Moreover, the researchers may find themselves effectively insulated from any contact with the mass of the rural population.

A final element in research is the increasing role of private research and extension in areas traditionally reserved for the public sector. It should be remembered that private research and extension has as its primary goal, the creation of private profit. This may coincide and be compatible with the goals of public research. However, there is no assurance that it will. Indeed, Trigo and Pineiro (1981) have viewed with alarm the rise of private research institutions in Latin America. They note that increased private research has been tightly aligned with (a) the deterioration of public research institutions, (b) the virtual elimination of research aimed at small farmers, and (c) an increasing inability on the part of the public sector to determine the direction of technical change. While little or no evidence exists to suggest that such is the case in the major sorghum producing nations, increasing private sector involvement will be a factor in sorghum research in the 1980s. The role such research will play needs to be given greater attention by policy makers.

Finally, we come to the farmers themselves, the kingpin in the entire research system. Yet, we find that their linkage with the rest of the system is probably the weakest of all. Despite certain outstanding exceptions, many sorghum farmers are virtually unaware of the existence of research and extension services, let alone actively receiving those services. This is particularly unfortunate in that sorghum farmers have developed, over the centuries, a substantial backlog of folk knowledge relating to the crop. While undoubtedly some of that folk knowledge is erroneous, the record shows that practices which evolved in folk systems are more often than not well suited to their respective environments. As agronomist Pierre Spitz has noted:

> Thus, it is necessary that scientists not be convinced of the superiority that their knowledge of the agricultural sciences confers upon them, but convinced of the richness of peasant know-how. Science begins in this domain as in most others with modesty and the capacity to admit one's ignorance, not with arrogance and contempt (1979, p. 278, our translation).

Processes of Research Decision-making

An understanding of the structure of the sorghum research system must also include an examination of the processes by which that research system functions. While it is necessary to view the sorghum research system as a broad social system embedded in, influenced by, and influencing political, social and economic institutions, the research system is also a social network consisting of individuals and groups of individuals who have needs, desires, goals, personality traits, and various experiences and who attempt to influence one another in a variety of ways. While scientists are often seemingly free to study what they wish, their interests may be strongly influenced by social psychological factors as well as structural factors such as political and economic forces. What scientists study, the methods and theories they use in their studies, and how they choose to present their results are all decisions which may be influenced by nonscientific variables.

The demographic background of researchers and research administrators may influence, or be related to, the nature of agricultural research on sorghum. For example, Zuckerman (1977) in her study of Nobel Prize winning scientists found that they tended to have a number of demographic similarities such as having studied at one of only a handful of universities and being comparable in age. Who are the sorghum scientists, research administrators and policy makers? What is the nature of their background and education? How homogeneous or heterogeneous are their backgrounds and experiences? Is there a potential insularity in their educational and research experiences?

These educational experiences and backgrounds are important components of the larger process that is known as career socialization. The career of an agricultural scientist entails numerous experiences and decisions which are continuously being reexamined and reformulated. Important choices entail the field, discipline, or crop specialization itself, the specific research problems or questions, the choice of research methods and approaches, the identification of key concepts and the theoretical orientation. The processes by which these essential decisions are made are important for understanding the current products as well as the future possibilities of the research system. A number of people in a scientist's career may impinge on those decisions. These potential socializing agents may include one's immediate supervisor, a colleague in the scientist's department or research institute, a colleague in another agricultural science department or another research institute, a research assistant or technician, a graduate or postdoctoral student, a former professor, a director of one's research facility, a client or potential user, or a research review committee. How do these various sources of influence affect the various dimensions of research for sorghum scientists? At what point in their careers are particular sources influential and who are the most important persons in shaping these research decisions?

Equally important is an understanding of the nature of each scientist's research on sorghum. To what extent can it be characterized as basic, applied or development? Do scientists divide their time between research, administration, extension, and teaching? How does this affect the quantity and quality of their work?

Another important dimension in the process of research on sorghum is the role of both formal and informal communication. Carol Ganz (1976, p. 387} recently examined the role of scientific communication in the process of technological innovation and concluded that "through improved understanding of the information flow and management variables involved in the innovation process, considerable leverage can be exerted to improve the Research and Development process, and with it, reduce the costs or increase the benefits of research investment." Scientists communicate in a variety of ways but the nature of that communication and its effects on research are not clearly understood. They communicate formally through the publication of journal articles, bulletins, abstracts, reports, and newsletters. They also circulate preprints and read and exchange papers at professional society meetings and seminars such as this one on Sorghum in the Eighties. In addition, scientists utilize data bases and information centers such as the Sorghum and Millets Information Center (SMIC) which seek to collect, collate, and disseminate comprehensive information on sorghum to research workers all over the world. The impact of these various sources of information on research processes and products needs to be more fully assessed. Which sources do sorghum scientists utilize to disseminate their findings? Which sources do they subscribe to and review regularly? How important are each of these formal communication sources in their research?

While the formal communication system is generally recognized as very important to the research system, a neglected area is the informal communication network. Importantly, two recent studies (Kelly, Kranzberg, Carpenter and Rossini 1977) concluded that people and not formal channels of communication are more effective for transmitting technical information. Furthermore, these two studies admonished scientific and technical information suppliers to concede that the formal channels of communication are not that useful to researchers in organizations and that informal channels will continue as the dominant form of communication. Information is needed on the nature, extent and impact of the informal communication networks. With whom do sorghum researchers communicate regarding their research and how often? Is it only with scientists in their own departments and institutions or do they converse across disciplinary and institutional boundaries? What is the nature of sorghum scientist involvement with various national technical committees relevant to sorghum research? What are the formal and informal communications among scientists in national sorghum research programs and related grain programs? To what extent are there communication linkages between national sorghum research programs in different countries? What are the communication networks between these scientists and international programs such as ICRISAT and the U.S. Agency for International Development sponsored Grain Sorghum/Pearl Millet Collaborative Research Support Program (INTSORMIL)? What is the nature of contact between members of the sorghum research community and other nonagricultural scientists, administrators, funding agencies and extension staff, and farmers? Finally, how do these patterns and processes affect the outcomes of research?

These issues and questions regarding the processes of research are important for better understanding how knowledge of sorghum is produced and diffused within the scientific community and to the public at large. Moreover, answers to these questions of the dynamics of sorghum research are also important for improving the effectiveness and efficiency of sorghum research.

Research Products

The most effective and efficient research system, however, is of relatively little value if the products it creates do not serve their intended purpose. We take it as axiomatic here that sorghum research in developing countries is aimed at improving the level of living of peasant producers and increasing food available to consumers. Yet, as Dumont and Cohen (1980, p. 44) have noted, "in the final analysis, food on the market is irrelevant as a remedy for hunger unless it can be bought by those who need it." This means that focusing upon the technical question of increasing sorghum production must be, and always is, inextricable from the social question of the distribution of wealth and power. As Pearse (1980, p. 6) notes in his summary of the United Nations studies on the Green Revolution, technical change is always associated with a change in social relations. The problem for both the scientist and the research administrator in the eighties will be how to assess the various kinds of potential products of sorghum research so as to choose those which will have the most beneficial effects on producers and consumers alike. This problem is compounded by the fact that there are vast differences amongst sorghum producing nations in infrastructure, in class structure, and in social relations (Ryan and Binswanger 1980).

As we look to the eighties, we need to know more about how to assess new technologies, how to improve the effectiveness of the research system in terms of both its products and its processes, and how to establish a productive dialogue among small fanners, consumers, and researchers. Such tasks are made even more urgent by the necessity of supplying food for an increasing population.

Conclusions

In sum. sorghum research like other agricultural research, requires an integrated institutional structure which is adequately funded and devoted to food production for human consumption. The mufti-layered structure should consist of international, regional, national and local research institutions coordinated to serve both producers and consumers. This research system requires a community of well trained scientists who have adequate research resources and sufficient incentives to pursue relevant research. In addition, it requires effective formal and informal scientific communication networks among all scientists involved in sorghum related research. Finally, this system requires procedures for assessing the multiple consequences of current research (e.g., yield stability, food quality, labor displacement, socioeconomic equity) and for evaluating alternative research trajectories. These are the challenges of the eighties.

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Session 8 Socioeconomic Considerations

J. 6. Ryan* Discussant—1

Rather than review the five papers I was asked to discuss in the socioeconomic session of the "Sorghum in the Eighties" symposium, I propose to build upon some of their themes and add a few of my own. I will take a somewhat broader view of the constraints to sorghum production, its marketing, and the conduct of research than the authors of the papers. This is not meant to undermine their useful contributions but to complement them.

The paper includes a discussion of past and future trends in world sorghum production, consumption and demand which highlights the particular problems which the countries of sub-Sahara Africa may face in the 1980s. The importance of documenting and understanding the adoption of "mature" sorghum innovations in the context of ex ante design of subsequent new technologies is then addressed. The role of markets, infrastructure, delivery systems, and related policy initiatives are considered as they affect sorghum production and adoption. Criteria for determining the allocation of research resources amongst the various sorghum producing regions of the SAT are included. Some discussion of possible future priorities in sorghum breeding follows with the penultimate section devoted to the potential contribution that a farming systems approach to sorghum research could make in the eighties. A concluding statement then emerges.

Sorghum Trends and their Implications

The world area of sorghum now exceeds 50 million hectares (Table 1). It has been growing since 1964 at the rate of 0.37 million hectares annually.[1] When combined with the steady growth in yields of 25 kg/ha per year over the same period (2.2%), the area expansion has led to an annual trend growth in sorghum production of 1.66 million tonnes.[2] This represents a compound annual growth rate of production of 2.90%. We have estimated from a study by the World Bank (1977) that up to 1985 the annual rate of growth in demand for coarse grains in developing countries will be 3.60%. This compares with the estimate of Aziz (1976) for the less developed market economies of 3.55% from 1980 to 1990 and 3.57% from 1980 to 2000. FAO (1971) estimates annual compound growth rates of demand for coarse cereals from 1980 to 1985 of 2.69% for developing market economies.[3] These figures suggest that demand pressures for sorghum may build in the 80s and exceed historical growth rates in world production.

Sorghum production has grown at an annual rate of 3.80% in the developing countries of the semi-arid tropics (SAT) from 1964 to 1978. This is a much better record than in the developed

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1. Derived from linear trend lines fitted to FAO data from 1964 to 1978. The equation is: Area ('000 ha) = 45230 + 370t, where t = time in years and the figure (3.4) in parentheses is the estimated t-value of the coefficient on time. The year 1964 implies t = 1. The R^2 was 0.48.
2. The respective linear trend equations are: Yield (kg/ha) = 1008 + 25t with R^2 of 0.74; and Production (6.0) ('000 metric tons) = 45051 + 1657t with R^2 of 0.92. (12.1)
3. Additional demand not accounted for in the above projections may also derive from expanded use of sorghum as a source of feedstock for production of alcohol to replace oil. This is already occurring in the U.S. and Brazil (Schaffert and Gourley 1982).

International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81. Patancheru, A.P., India. Patancheru, A.P. India: ICRISAT.

Table 1. Annual average area, production, and yields of sorghum in various regions of the world, 1975-78.*

Regions		Area ('000 ha)	Production ('000 tonnes)	Yield (kg/ha)
Semi-arid tropics				
A. Developed market economies				
Oceania		485	924	1905
	Subtotal (A)	485	924	1905
B. Less developed market economies				
Africa South of Sahara		12 973	8 741	674
North and Central America		1 473	3 845	2610
South America		2 455	6 607	2691
Asia		17 832	12 298	690
	Subtotal (B)	34 733	31 491	907
	All SAT (A+B)	35 218	32 415	920
Rest of the world				
C. Developed market economies				
Africa South of Sahara		356	418	1174
North and Central America		5841	19 137	3276
Asia		4	16	4000
Europe		144	560	3889
Oceania		—	—	—
	Subtotal (C)	6 345	20 131	3172
D. Less developed market economies				
Africa South of Sahara		632	778	1231
North and Central America		331	383	1157
South America		271	613	2262
Asia		17	15	882
Europe		—	—	—
Oceania		—	—	—
	Subtotal (D)	1 251	1 789	1430
E. Centrally planned economies*				
	Subtotal (E)	7 839	11 959	1526
Rest of world (C+D+E)		15 435	33 879	2195
World (A+B+C+D+E)		50 653	66 294	1309

a. Source: Food and Agriculture Organization (various years).

b. Before the early 1970s, FAO reported China's sorghum production as virtually nil. Instead, it was reported under millets. In the mid-1970s. FAO began reporting China's sorghum production separately. We estimated earlier production as being half of the millet figures based on the proportions published by FAO after the mid-1970s.

countries, where production has grown by only 1.49% during the same period.[4]

It would seem that the developing countries, including those in the SAT, will be in a more adequate supply-demand balance for coarse grains in the 1980s and 1990s than the developed countries. However, there are differences in sorghum production trends in the various regions of the SAT which suggest there will be substantial regional imbalances between supply and demand (Table 2). Only in the North, Central, and South American and other Asian SAT regions has sorghum production grown faster than population.

The United States Department of Agriculture (USDA 1980, p. i) in a recent study pointed out: "Sub-Saharan Africa is the only region in the world where per capita food production declined over the past two decades " In 1978, the index of per capita food production in the 40 countries of Sub-Saharan Africa (SSA) was about 21% below the level in 1961-65. In Asia, the index rose 15% during the same period, while in Latin America it rose 13% (USDA 1980, p. 2). Projected food import gaps for SSA in 1990 under various assumptions range from 9.5 to 21.1 million tonnes. In addition, estimates of unmet food needs in 1990 required to bring diets up to minimum calorie consumption levels of 2300 (cal/person per day) range from 9.1 to 13 million tonnes.[5] Current food imports in SSA cost about 600% more than they did in 1970 and represent 220% of the 1970 volume (USDA 1980, p. 6). As a result there are severe balance of payments problems. The present and prospective food and nutrition problem in SSA is both a production and distribution problem. This is unlike parts of Asia and Latin America where the problem is primarily one of distribution. In SSA "Aggregate supplies are inadequate—even assuming totally equalitarian (sic) distribution" (USDA 1980, pp. 49-50). For the above reasons, it would seem that the major agricultural research and development efforts of the 80s in sorghum should focus on the SSA region.

Table 2. Annual compound growth rates of sorghum production and population in seven regions of the SAT.

Region	Annual growth rates (%) Sorghum production 1961-78	Population (projected) 1978-1990)
India	1.15	2.23
Eastern Africa	2.19	3.25
West Africa	-0.39	4.14
Southern Africa	1.82	2 89
Other Asian	3.36	2.66
North, Central, South America	12.50	2.84
Near East	-2.03	3.26

Sources. FAO and projections from the International Food Policy Research Institute data tapes.

Arakeri (1982) points out that the projections of the National Commission on Agriculture, NCA, indicate a satisfactory supply-demand balance for cereals in India in the year 2000, including coarse grains, provided yields (in the case of sorghum) could be increased by 70%. Yields of sorghum in India have been growing annually by 1.56% from 1960 to 1978. At this rate it would take to the year 2010 to reach the yield of 1.2 t/ha used by the NCA to arrive at its conclusion on the supply-demand balance for sorghum. If yields grow at 2.16% annually, the target could be achieved by 2000. This growth rate is well within the range of possibilities as, since 1970, yields have grown at more than 7% per year.

Arakeri suggests that demand for sorghum for human food in India in the future is not projected to rise nearly to the same extent as demand for sorghum for animal food purposes. This is supported by Aziz (1976), who estimates that for the less developed countries coarse grain demand for human food will grow by only 2.5% annually between 1970 and 2000, whereas coarse grain feed demand will grow by 5.3%. Expenditure elasticities derived by Radhakrishna and Murty (1980) for India indicate a much larger propensity to consume meat, fish, eggs, and milk products than coarse grains as incomes rise (Table 3). As the conversion ratio of grain to meat, poultry, eggs, and milk is very large, this will cause the derived demand for coarse grains, to feed ani-

4. The growth rates have been derived using FAO data (various years).

5. The USDA report points out that these estimates are comparable with those recently made by FAO and the International Food Policy Research Institute (IFPRI).

mals, to grow rapidly in future. This will have implications for sorghum breeding strategies in the SAT in the 80s. In particular, there may be merit in conducting separate breeding programs for food and feed purposes in the SAT countries, perhaps also including evaluation of high sugar sorghums being developed in the U.S. and Brazil.

Adoption Studies and Technology Design

High-yielding varieties (HYVs) of sorghum have been available in India for some 15 years. Latest figures put the adoption rate at only 16% of the sorghum area (Fig. 1). In their paper, von Oppen and Rao (1982) present data on trends in the contribution of the various states to India's total sorghum production. When these are compared with state yield trends, some puzzles emerge. Sorghum yields in Gujarat and Karnataka have been growing at rates far in excess of any other state. Since 1954-57 average yields in both states have doubled; yet during the same period their shares in India's sorghum area declined by 2 and 6.4 percentage points, respectively.[6]

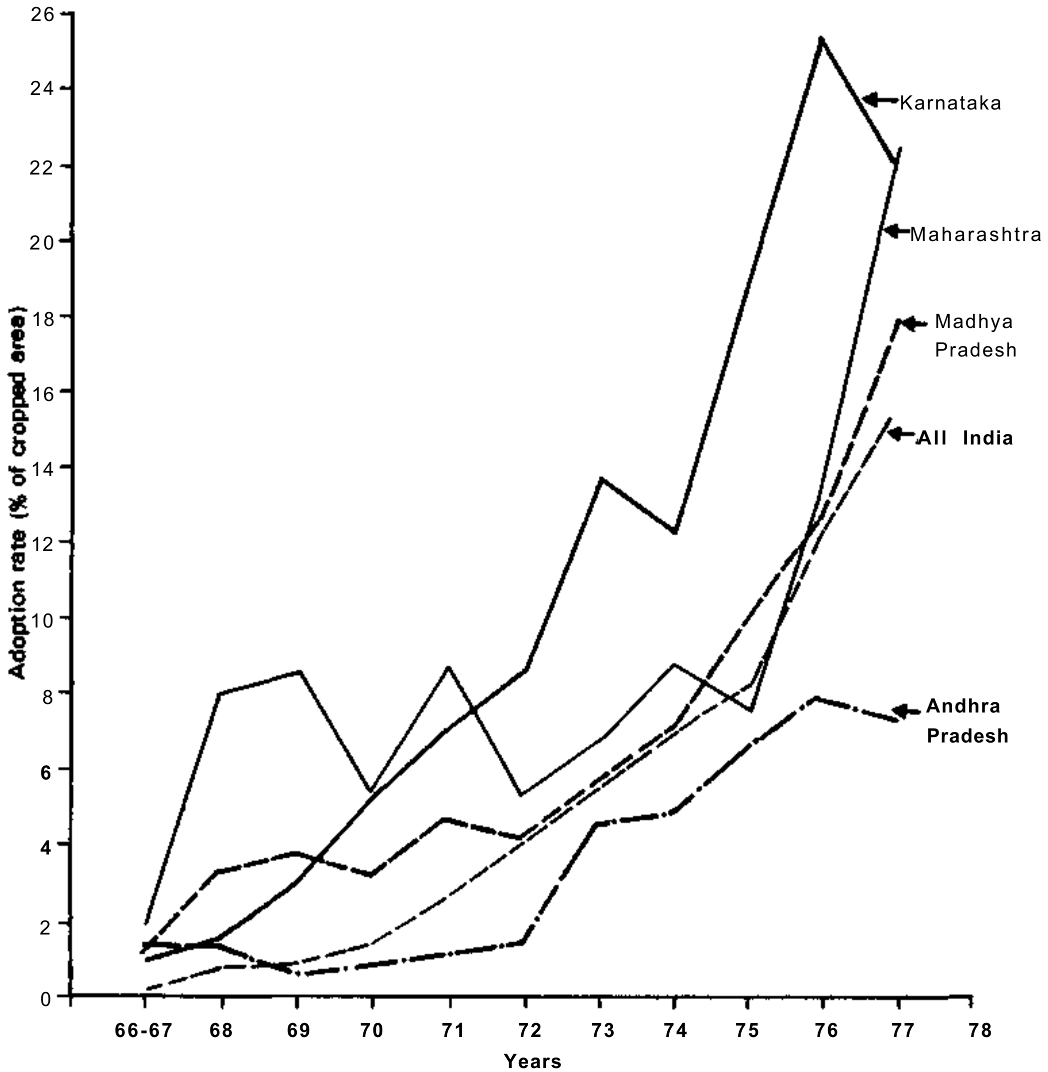
Why did these states, where productivity has been growing fastest, and which presumably therefore had an increased comparative advantage in sorghum production, become less important sorghum producers? Why did Maharashtra increase its share by more than any other state (7 percentage points) during a period when its sorghum yields increased by only 40%? Part of the explanation for Karnataka's yield performance may be the higher sorghum prices von Oppen and Rao report for that state, which might have caused it to record the highest rate of adoption of HYVs (Fig. 1). But if sorghum prices in Karnataka have been so high, why has it had the lowest marketed surplus (7.6%), and why has its share in India's sorghum production declined so substantially? By contrast. Gujarat has the second highest marketed surplus (23.4%), and only a 4% rate of adoption of HYVs. yet its yields have been growing at the highest rate. This requires further study.

In countries like India where "mature" sorghum HYV innovations have been available for many years there is a need now to study the reasons for apparent ceiling rates of adoption. To date, eight hybrids and seven varieties have been released by the All India Coordinated Sorghum Improvement Project (Arakeri 1982). Experience in the ICRISAT village-level studies (VLS) in South India would not support Busch and Lacy's (1982) claim that most sorghum farmers are unaware of the existence of research and extension services and of the HYVs they purvey. Simply because adoption is low for one crop in the farming system does not allow one to conclude this. We find that the same Indian farmers who grow hybrid cotton, HYV castor and paddy, and use fertilizers and chemical sprays on them, often do not grow HYVs of sorghum. Rastogi and Annamalai (1981) found that in the rainy season in five dryland centers in India well served by extension agencies and scientists, average adoption of HYVs of sorghum was only 22%, with a range of from zero to 100%. This was in spite of demonstration plots which yielded 172% more than traditional plots and increased profits by 90% (Rastogi 1981). Rastogi and Annamalai found that adoption of recommended fertilizers and plant protection measures was equally poor (Table 4).

The high cost of improved seeds and susceptibility of the high-yielding varieties to pests and diseases were the major reasons given by farmers for nonadoption. High prices, fear of crop failure if rains were inadequate, and capital constraints were stated to be the reasons for nonadoption of fertilizer recommendations. Plant protection was ignored largely because of its high cost, but also due to the lack of technical advice on timing and spraying techniques. The question of nonadoption of "mature" innovations hence would seem to be related more to the nature and characteristics of the technology available rather than to the availability of information and the socioeconomic characteristics of potential adopters.

In a study of the reasons for the leveling off of adoption of hybrid maize at 55% of the planted area in El Salvador, Walker (1980) found the most significant determinant of adoption was potential drought stress in a region. Nonadopters were generally those who had to contend with erratic rainfall regimes and shallow soils in the production of maize. Farm size, tenure, schooling, and use of institutional credit did not constrain adoption as much as environmental variables related to location-specific topographical, climatological, and edaphic characteristics. The relative lack of de-

6. These were the largest declines among the states.



Source: The Fertilizer Association of India (various editions) and Government of India (1980).
Note: Only major producing states are shown.

Figure 1. Adoption of HYVs of sorghum in India.

velopment of improved location-specific HYV sorghum cultivars in India in favor of those with wide adaptability, may well be part of the explanation for the ceiling adoption rates we observe in Figure 1.

An urgent research priority in the 1980s is to undertake studies patterned on the Walker model in India and in other countries having "mature" sorghum technologies and low ceiling adoption levels. Only then will we be confident that the plea of Arakeri (1982) for development of more location-specific sorghum genotypes is the appropriate research strategy for achieving the sixfold increase in the area of HYVs in India projected for the year 2000 by the National Commission on Agriculture.

Farmers' perceptions of the risks of adoption of innovations were shown to be a major determinant of hybrid maize adoption in El Salvador by Walker (1981). Risk perceptions were far more important than risk aversion attitudes in explaining adoption behavior, and, as found by others, risk aversion attitudes were not influenced by the socioeconomic characteristics of farmers. Far-

Table 3. Expenditure alasticities for "other cereals' and meat, fish, eggs, and milk in India.

Level of total real monthly expenditure*	Rural			Urban		
	Other cereals[b]	Meat, fish and eggs	Milk and milk products	Other cereals[b]	Meat, fish, and eggs	Milk and milk products
(Rs/capita)						
0-18.0	0.881	0.742	2.533	1.041	0.612	1.200
18.1-28.0	0.557	1.170	3.033	0.871	0.815	1.945
28.1-43.0	0.511	0.977	1.065	0.962	0.972	1.690
43.1-75.0	0.186	0.827	1.399	0.363	1.025	1.183
> 75.0	0.172	0.503	0.585	-0.450	0.743	0.757

Source: Radhakrishna and Murty (1980. p. SO).
a. In constant 1969-70 prices.
b. Includes sorghum, pearl millet, maize, barley, small millets, finger millets, chickpea, and their products.

Table 4. Adoption of recommended technology for sorghum in rainfed project acreas In India, 1976/77 to 1979/80.

Technology components	Units (%)	Rainy season		Postrainy season	
		Mean	Range[a]	Mean	Range[a]
Adoption of improved seed	farmers	22	0-100	87[b]	62-95[b]
Adoption of improved seed	area	16	na	77[b]	na
Use of fertilizers	farmers	25	1-79	41	14-79
Use of fertilizers	area	22	0-80	18	9-34
Use of recommended levels of nitrogen fertilizer	farmers using >50% recommendation	57	10-85	45	20-47
Use of plant protection measures	farmers	25	3-47	27	0-50
Use of plant protection measures	area	10	2-21	11	1-30
Use of interculture and weeding	farmers	96	86-100	95	93-100

Source: Rastogi and Annamalai (1981).
a. The ranges refer to data over the 4 years for the five centers in the case of the rainy season and four centers in the case of the postreiny season.
b. it is likefy that the HYVs in this case are based on the Maldandi (M-35-1) locally improved cultivar released in the 1930s. This could explain the high levels of adoption.
na = not available.

mere correctly perceived the differential performance of hybrids and local varieties under drought stresses in the various regions studied. The objective probabilities of drought generally' supported the beliefs of farmers. Nonadopters believed that drought was more intense in their village and that local varieties were superior to hybrids in withstanding or escaping drought.

In a linear risk programming study in Northeast Brazil. Goodwin et al. (1980) showed that even with high levels of risk aversion, new sorghum technology should be adopted by farmers even if risks are perceived by farmers to be higher than they are. Reducing risk aversion to nil from moderate levels only increased farm incomes 46% by employing optimum changes in enterprise and technique choices, whereas removing risk misperceptions to nil increased incomes by 63%. If risk misperceptions were absent, then present levels of farmer risk aversion were shown to not result in vastly different choices of technique and farm incomes.

Both Walker and Goodwin et al. suggest high payoffs to the conduct of on-farm research and demonstrations to enable farmers to correctly perceive the yield risks they might face with new sorghum technologies. This must be a priority high on the research agenda for the 80s. We should not concern ourselves with the design of technologies with differential risk attributes in the belief that this will be required to ensure adoption by both risk averse and risk neutral farmers. The majority of farmers in developing countries do not seem to differ markedly in their risk attitudes according to the accumulating evidence from economics research.

Arakeri (1982) contends that fertilizer use on sorghum in India is limited to irrigated areas and that credit constrains its use by small farmers. Busch and Lacy (1982) suggest SAT sorghum farmers are poor and unlikely to use intensive technology. Jha et al. (1981) found that in 16 of 21 districts of SAT India more than 80% of fertilizer adopters applied fertilizer to unirrigated HYVs of sorghum. Rates of application were higher on Vertisols. Overall, most farmers fertilized more than 60% of their unirrigated HYV sorghums with N. and used 21-40 kg/ha on the land they fertilized. Coverage and rates were somewhat higher on irrigated HYVs (Table 5). This evidence would not support Arakeri, and Busch and Lacy.

In areas where HYVs have spread widely, Jha et al. (1981) discovered this led to a higher proportion of their area being fertilized, although there was no tendency for application rates to be higher. They suggest that districts having high rates of fertilizer application per ha signify the availability of regionally adapted, fertilizer-responsive HYVs. Those districts having a small proportion of crop areas fertilized have inadequate institutional infrastructure. Using this scheme they identify sorghum districts in India where technological, institutional, or both factors play a role in inhibiting adoption and use of fertilizers. This approach can be used to help plan research and investment strategies in the 1980s.

In a district analysis, Jha et al. (1981) found rainfall and credit were significant determinants of adoption and spread of N fertilizer use on HYVs of sorghum in India. However, they did not affect the rates of application of N. In a farm-level analysis, Jha and Sarin (1981) found that soil moisture status, timely sowing, farmers' education and experience, rotations followed, and fertilizer prices were important factors influencing fertilizer use. As variations in fertilizer prices in these data were generated by cross-sectional variability, Jha and Sarin suggest this implies regional imperfections in retail fertilizer trade and transport. They conclude there are therefore high payoffs to infrastructural improvements which will have the effect of reducing fertilizer prices and increasing fertilizer demand. This must be accompanied by improved physical availability of fertilizers to be effective. In Aurepalle village in Andhra Pradesh, we have found there was a substantial effective demand for fertilizers for use on rainfed crops when we ensured the physical supplies were available in the village itself, instead of in the nearby town. No credit was made available—all transactions were on a cash-and-carry basis.

The importance of credit in conditioning choice of technique—especially for small farmers, as emphasized by Jha and. Sarin (1981)—is illus-

Table 5. Modal classes of fertilizer application and spread of HYV sorghum In India, 1973/74.

	Modal classes			
	Application rates (kg/ha fertilizer)		Area fertilized (% HYV area)	
Nutrient	Irrigated	Unirrigated	Irrigated	Unirrigated
Nitrogen (N)	41-60	21-40	>80	>60
Phosphorus (P_2O_5)	31-40	21-30	>80	<40
Potassium (K_2O)	11-20	11-20	61-80	<40

Source: Jha et al. (1981).

trated by a linear programming analysis I performed using some factorial experiments conducted by the All India Coordinated Research Project for Dryland Agriculture. There were four technique choices possible, each having different costs and profits (Table 6). Land was limited to 5 ha and optimum plans were calculated for various amounts of working capital available to a farmer to invest in his land. No other constraints were imposed. Only after the farmer had access to more than Rs. 1000 of working capital (Rs. 200/ha) did the solution to the problem indicate that it was desirable to apply fertilizers to the CSH-1 hybrid sorghum (Fig. 2). If Rs. 1000 or less were available, CSH-1 with local inputs was only chosen. The balance of land which could not be sown to CSH-1 due to shortage of capital in such instances, would be leased out to others.

These results highlight the need for the design and demonstration of a range of technological options rather than a package of practices if we are to cater effectively to the great variability which exists among farmers, even within relatively homogeneous regions, in their resource endowment ratios and access to factor markets. These issues are addressed in more detail by Ryan and Rathore (1978) and Ryan and Subrahmanyam (1975).

Markets, Infrastructure, and Policy

It seems clear from three of the four papers in this session, and from the work of Harriss (1981) that marketing arrangements for coarse grains in the SAT countries, especially those in West Africa, adversely affect production and also probably technological change. Arakeri (1982) points out that sorghum/fertilizer price ratios in India are inferior to those of rice and wheat. Support pricing policies for coarse grains are virtually ineffective in India; when this is combined with their generally lower price elasticity of demand compared to rice and wheat (Radhakrishna and Murty 1980, p. 51) the pricing policy leads to substantial depressions in price in periods of abundant supplies.

Peterson (1979) has calculated the average "real"prices of farm commodities in wheat equivalents, expressed in terms of the kilograms of fertilizer (at local domestic prices) that could be purchased with them. Real farm prices are more favorable to farmers in the developed countries than to their counterparts in the developing countries. For the 12 developing SAT countries in Peterson's analysis, the average real price was 19, while for 22 developed countries the price was 35. Hence on average the production and sale of 100 kg of wheat grain equivalents in the 12 SAT countries would buy about half the fertilizer that it would buy if produced and sold in developed countries. Real prices in Niger are only 7, in Upper Volta 14, in Senegal 19, and in the Cameroons 16.

Peterson's analysis suggests these distortions from world price levels involve social costs, in 11 of the 12 SAT countries which he considered, of a total of U.S. $ 1970 million annually. Niger's social

Table 6. Profits and costs of alternative sorghum activities in a linear programming exercise.

Activities	Profits	Costs
	—Rs/ha—	
Local sorghum variety with local inputs	500	100
Local sorghum variety with 100 kg N/ha	973	535
CSH-1 sorghum hybrid with local inputs	1607	200
CSH-1 sorghum hybrid with 150 kg N/ha	3300	853
Leasing-out land	200	—

Source: All India Coordinated Research Project for Dryland Agriculture (unpublished data).

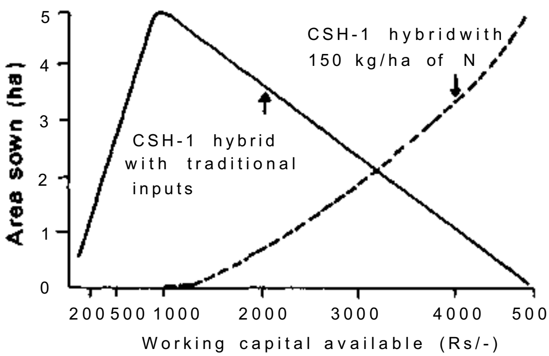


Figure 2. Optimum choice of activities for maximizing profits on a farm of 5 ha.

costs represent 29% of its national income. Using agricultural supply response elasticities, which Peterson estimates to be between 1.25 and 1.66, he calculates that if the 26 developing countries he considered had the real price levels of the 26 developed countries (37) over an extended period, their 1969 output would have been about 220 million tonnes (63%) higher than it actually was. Even if we use the supply elasticities mentioned by von Oppen and Rao for India of 0.2 to 0.8, the adverse effects of agricultural price distortions for developing country food supplies are enormous. These distortions appear to be greatest in the African countries where the USDA (1980) projects the greatest food supply problems are likely to emerge in the 1980s.

Sherman and Ouedraogo (1982) caution us against advocacy of single solutions to the problems of grain marketing in West Africa. Region-specific solutions will not suffice, as each state (except Mauritania) has a monopoly on grain marketing. There are differentials in the physical infrastructural characteristics of each region and these affect the structure of private or parallel grain markets. One wonders why grain marketing research in West Africa concentrates so much on the marketing parastatals and the presence or absence of market competition. I estimate from Harriss' (1981) figures that less than 6% of grain production is marketed by parastatals in West Africa (Table 7). It is difficult to believe parastatals could be distorting grain prices all that much, even though they trade between 20 and 40% of the marketed surplus (Table 7, USDA 1980, p. 197, Sherman and Ouedraogo 1982). Parallel market prices are also 2-3 times higher than "fixed" prices in the official market (USDA 1980, p. 57).

There would appear to be greater payoffs in the 80s to policy research on rationalization of input prices, food grain trade, and imports. The USDA study (1980, pp. 343-345) shows that the largest potential impact on food supplies in SSA comes from a scenario where roads and infrastructure increase supply response elasticities. Self-sufficiency ratios in Central Africa were estimated to increase by 60-100% in this event, allowing it to become a net exporter instead of a net importer of grains. In a yet unpublished report, von Oppen and Rao (1980) have estimated smaller but significant effects of improvements to roads, communications, and density of agricultural markets on agricultural productivity. Unless these issues are explicitly addressed in the 1980s, then attention to domestic grain marketing issues and development of improved sorghum technologies may be like pushing on a string.

More studies are required in the 80s aimed at quantifying the impact of current national price policies for coarse grains vis-a-vis their major competitors—rice, wheat, groundnuts, cotton and other "commercial" crops. For example, these policies might explain the decline in sorghum's share of India's cereal area from 19.6% in 1954-57 to 15.9% in 1975-78 (von Oppen and Rao 1982), and the precarious nature of food supplies in the Sahel (USDA 1980; Sherman and Ouedraogo 1982; Harriss 1981). The USDA (1980. pp. 366-377) concludes that urban food habits in SSA need to be changed away from imported rice and wheat, thus increasing demand for traditionally grown grains (maize, sorghum, millets). It is doubtful if this can be achieved by introducing new processing technology and changing consumer tastes as the USDA proposes. The effective way would be to curtail imports of rice and wheat. This will help food self-sufficiency goals by increasing demand for and prices of traditional grains, improve deteriorating balance of payments, and create essential linkages between urban and rural areas where few exist at present.

Research Resource Allocation Issues

Which regions of the developing world should receive the highest priority in the allocation of scarce sorghum research resources in the 1980s? Unfortunately, the only paper which addresses sorghum research (Busch and Lacy 1982) fails to consider this important issue. They stress the importance of informal communication channels in the conduct of research and urge studies of how these patterns affect the outcomes of research. I completely agree with their assessment of the need for a dialogue between the farmer and the researcher in a farming systems approach. However, I fear that their agricultural research Model IV goes too far in ignoring the importance of research station activities. Without explicit recognition of the role of what Norman et al. (1981) refer to as the "body of knowledge", built up from cumulative basic and applied research, the quest for viable technologies from dialogue between farmers and scientists may not be fruitful.

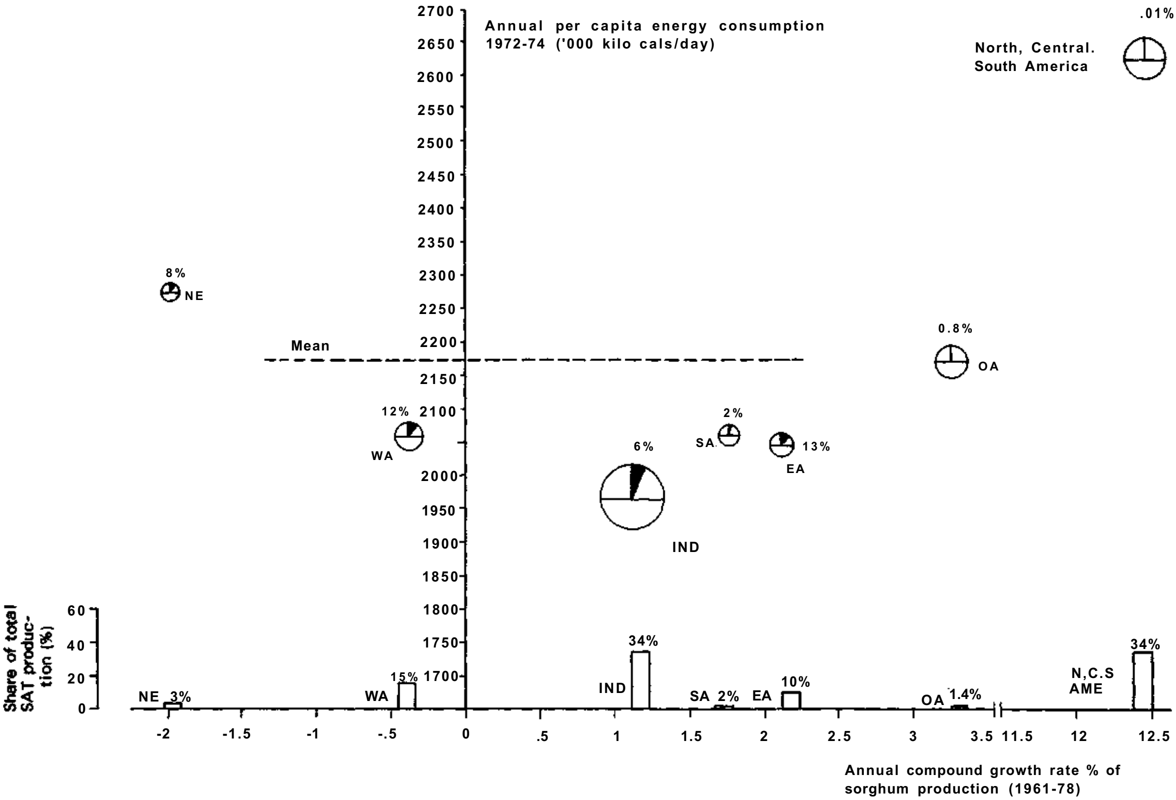


Figure 3. Growth rate of sorghum production and contribution of sorghum to total calorie intake in SAT regions. NE = Near East; WA = West Africa; Ind = India; SA = Southern Africa; EA = Eastern Africa; OA = Other Asia; N, C. S Ame = North. Central, South America.

Table 7. State intervention in grain marketing in West Africa.

Country	Parastatal	Marketed surplus traded by parastatal (%)	Proportion of production represented by marketed surplus (%)	Proportion of production marketed by parastatal (%)
Niger	OPVN[a]	20	10-16	2-3.2
Upper Volta	OFNACER[b]	20	15	3
Mali	OPAM[c]	≤40	15	≤ 6
Senegal	ONCAD[d]	≤30	15	≤4.5

Source: Harriss (1981)

a. Office des Produits Vivriers du Niger.

b. Office National des Cereales.

c. Office des Produits Agricoles du Mali

d. Office National de Cooperation et d'Assistance pour le Developpement.

Table 8. Criteria used in establishing indices for the regional allocation of research resources in the SAT.

	SAT regions						
Criterion	India	Eastern Africa	West Africa	Southern Africa	Other Asia	N.,C.,S. America	Near East
Per capita income (GNP in U.S. $)	140	178	324	237	223	1288	2171
Annual per caput income growth per unit income	0.0114	0.0081	0.0115	0.0036	0.0107	0.0032	0.0025
1978 population C000)	660 976	82 033	128 098	71 564	172 555	240 311	50 263
Projected annual population growth: 1978-1990 (%)	223	3.25	4.14	2.89	266	2.84	3.26
Production trends: annual compound growth[b] (%)	1.15	2.19	-0.39	1.82	3.36	12.50	-2.03
Present food status[a] ('000 kilo cals per caput)	1967	2043	2062	2062	2169	2637	2274
Sorghum's contribution to regional food calories[a] (%)	6	13	13	2	1	0	8
Regional contribution to SAT sorghum production[a] (%)	34	10	15	2	1	34	3
Yield stability[a] R^2 of linear trend)	0.54	0.15	053	0.47	0.55	0.88	0.03
Man/land ratio (people/ha)	382	2.98	1.61	2.90	3.55	2.60	2.78

Source: von Oppen and Ryan (1981)

a. Crop-specific indices. All others are region-specific.

In a recent paper, von Oppen and Ryan (1981) have used 10 criteria to attempt to determine desirable patterns of regional research resource allocations for ICRISAT. These embrace both efficiency and equity concerns (Table 8). Five of the 10 criteria are presented graphically in Figure 3. The areas of the circles refer to the population in each region while the black segments refer to the contribution of sorghum to the regions' food calories. Depending on which criterion is judged by research managers to receive the heaviest weighting, the highest priority regions can be identified. For example, if present per capita food energy consumption is felt to be the primary factor which should determine regional sorghum research strategies in the 1980s, then India, with the lowest per capita calorie consumption of 1967, should receive the highest priority, whereas North, Central and South America should receive the lowest. Similarly, if poor historical production trends are considered most important, then the Near East rates first, and North, Central, and South America last.

The graphical analysis cannot accommodate all 10 research resource allocation criteria. Hence we have devised a composite numerical research resource allocation index (CONRRAI) that uses all 10 criteria. By assigning different weights to each criterion based on subjective assessments of the relative importance of equity versus efficiency concerns and adding up these weighted index values, we obtain for each region a composite index reflecting its relative priority. Two alternative weighting schemes are shown in Figure 4. Method A assigns twice as much weight to population, current food status, sorghum's contribution to calories, and the region's contribution to SAT sorghum production, compared with the other six criteria. Method B uses as the only criterion the region's share of SAT sorghum production. All other criteria are ignored.

If one were concerned solely with efficiency considerations then Method B might be utilized to guide research strategies. It suggests an equal emphasis on India and the North, Central and South American region, followed by West and then Eastern Africa. When equity concerns and other efficiency criteria are incorporated (Method A), the emphasis should shift from North, Central and South America and India to Africa, the Near East, and the other Asian regions. The USDA projections (1980, p. 308) of import and calorie gaps using 1979 prices and real incomes suggest perhaps even greater emphasis should be placed on West and Eastern Africa than Method A would indicate. The West African SAT region is estimated to have 74% of the total SSA food import gap by 1990 and 15% of its unmet food needs. Eastern Africa's comparable figures are 21 and 79%, respectively.

The above analysis suggests that a more regionally dispersed research strategy may be appropriate for ICRISAT sorghum research in the 1980s. In addition, it seems from accumulating research experience with sorghum and other crops that it may be difficult to develop improved cultivars at one headquarters location which will have wide adaptability across the SAT. Variations in day-length, duration, temperature, pests, and diseases seem to preclude this.

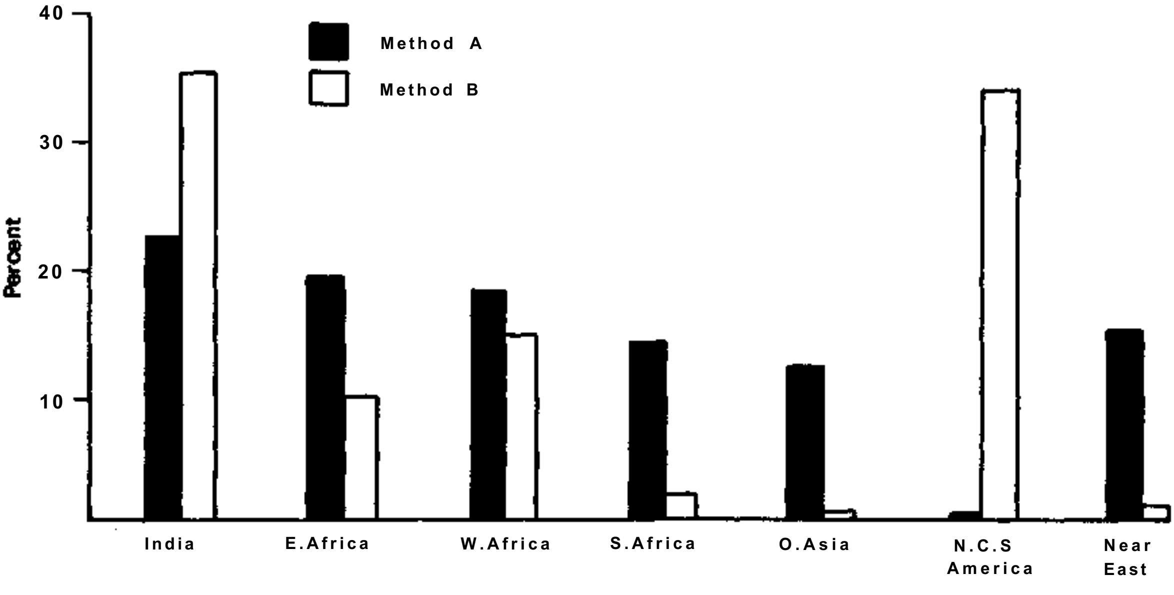


Figure 4. Suggested importance of each SAT region in determining the allocation of research resources using two methods.

Sorghum Breeding Strategies

In India, it is apparent from von Oppen and Rao's paper (1982) that fodder from sorghum is an extremely valuable commodity not to be ignored in breeding programs. Their analysis shows that HYV grain and fodder prices are both some 30% less than local cultivars. HYV grain yields are 160% higher than those of local cultivars, but fodder yields are 30% less. More research of this type is required in India to determine if the same relationships hold in other regions and in villages farther removed from the influence of large cities. It may be that the low levels of adoption of HYVs of sorghum in India, reported earlier in their paper, may be due in part to the inferior yield and price of HYV straw. Adoption studies need to explicitly account for this possibility, as von Oppen and Rao point out.

Studies are also required to determine if it is more feasible or efficient to attempt to breed dual-purpose sorghum cultivars, with the obvious tradeoffs in both fodder value and yield which this implies, or whether it is preferable to breed specialized types. The latter strategy would imply that farmers would grow the grain types for their foodgrain needs and, because their grain yields would be higher than for dual-purpose sorghums, land would be released for growing fodder sorghums. The answer to this question lies largely with the breeders' assessment of the likelihood of success of the alternative strategies and of the genetic tradeoffs implied in terms of relative grain and fodder yields. There may be less need for specialized sorghums in Africa where pressures on the land are not as great as in Asia. In Africa, extensive forms of technology have more relevance as Norman (1982) correctly points out, and hence development of dual purpose sorghums may be a preferred strategy. However, these issues require more research.

Irrigation has more than doubled in the last 20 years in seven of the SSA countries (USDA 1980. P. 113), and projections are for a further substantial growth in the 1980s. For Asia, various projections indicate a minimum growth of one-third in the net area irrigated in the 1980s (Gasser 1981). Should sorghum breeders devote resources to the development of HYVs suited to irrigated agriculture or to rainfed conditions? It would no doubt be easier to increase yield potentials and stability under an irrigated regime. Whether sorghum would be acceptable as a major part of the cropping systems in large-scale irrigation schemes is however questionable. Worldwide experience suggests that it is primarily crops such as paddy, sugarcane, cotton, and groundnuts which are grown in such schemes. As long as governments are unwilling to set fees for water which will cover its real costs and charge on the basis of volume, it is doubtful if sorghum would displace paddy and sugarcane, the most irrigation-intensive crops. Cotton and groundnuts are generally export crops facing relatively elastic demands, in contrast to sorghum (von Oppen and Rao 1982). Unless sorghum became an export crop and/or had effective price support policies, it is doubtful if sorghum breeders should devote a large proportion of their resources to development of cultivars suited to irrigated conditions.[7]

In papers by Jha and Sarin (1981, p. 68) and Jha et al. (1981, p. 61) a plea is made by the authors for development of regionally-adapted, fertilizer-responsive cultivars of sorghum for India. They claim that it is not the low-value nature of sorghum that has led to lack of fertilization of traditional cultivars, but their lack of fertilizer-responsiveness. A breeding strategy oriented towards yield and yield stability, which is the desirable course for Asia, may however find that these two objectives are difficult to achieve at the same time. In the developed non-SAT countries where yields exceed 3.3 t/ha, yield variability is six times greater than in the less developed SAT countries having yields less than 1 t/ha (Table 9). The experience seems to be that higher average yields imply greater variability.

Farming Systems Research

I agree with Norman (1982) that sorghum research in the SAT must be conducted within a farming systems research framework. Improvements to sorghum will have implications for other components of the farming system. An example of this would be the introduction of short-duration HYVs in the Vertisol assured rainfall regions of India which exacerbate labor and animal draft power bottlenecks at harvest, drying, and threshing times. These same farmers sow post-

7. Assuming these cultivars would be different from those that would result from a strategy aimed at breeding for rainfed conditions.

Table 9. Sorghum yield trends (1964-1978) and their variability in five producing regions.

Region	1978 trend yield (kg/ha)	Unexplained variability about linear yield trend 100 $(1-R^2)$	Number of countries	Annual compound growth in yields (%)
Developed non-SAT market economies	3308	91	37	0.7
Developed SAT market economies	2012	66	1	2.6
Centrally planned economies	1912	92	13	1.9
Less developed non-SAT market economies	1428	97	99	1.1
Less developed SAT market economies	935	14	47	3.2
World	1383	26	197	2.2

Source: Derived from FAO (various years).

rainy season crops like wheat, chickpeas, safflower as well as irrigated paddy at the same time as the HYV sorghums require the above operations.

Farming systems research by breeders, agronomists, and economists has shown that traditional sorghum cultivars in Africa respond to improved fertilization and management (USDA 1980. p. 142). Improved sorghum cultivars such as E-35-1 in on-farm tests in Upper Volta were no better than traditional cultivars when both were grown under improved management and fertilization, except in small areas near the village compounds. Cultivar E-35-1 also performed better than locals when animal traction was employed (Matlon 1981).

Labor constraints in Africa are much more severe than they are in Asia and call for quite different improvement strategies, as Norman (1982) correctly points out. For example, creating labor bottlenecks in Asia may be advantageous for landless labor as such bottlenecks tend to increase their employment probabilities and wage rates. In Africa, where there is not generally a landless labor group, this consideration becomes irrelevant and the possible adverse effect of labor bottlenecks on technology adoption by farmers becomes paramount. The latter effect of course also arises in Asia, but avoiding bottlenecks altogether to encourage adoption implies a tradeoff in potential benefits to wage labor in Asia, which is not the case in Africa.

For all the above reasons then it is clear that breeders, pathologists, entomologists, agronomists, soil and water management specialists, and social scientists must work closely together in a farming systems research mode if technologies are going to be developed which are in fact viable at the farm level under these differing resource endowment situations. This may apply particularly to Africa where the strategy will not necessarily be to enhance yields per hectare, but rather yields per man-hour.

More interdisciplinary research in on-farm situations is required where a whole-farm assessment of prospective sorghum technologies can be made. This should involve a judicious mixture of "rapid rural appraisal" techniques such as the *Sondeo* method used by Hildebrand (1977) in South America, complemented by in-depth longitudinal studies of the type ICRISAT has been conducting in India since 1975 and has initiated in West Africa in 1980 (Binswanger and Ryan 1980).

Conclusions

It seems clear that using a range of criteria, including efficiency and equity concerns, research and development (R and D) in sorghum in the 1980s should focus especially on Sub-Saharan Africa. A dual strategy in sorghum breeding is required for the African context—a short- and a long-run. I do not quite agree with Norman (1982) who maintains that delivery systems are a necessary precursor to successful HYV sorghum breeding programs in Africa. Rather, the reverse may indeed be true: that is, unless there is a derived demand for changing delivery systems in rural areas of the semi-arid tropics which emanates from the availability of improved varieties or hybrids, we may never see a change in these delivery systems. This is a long-run strategy. It is difficult to envisage that delivery systems will be improved in the absence of, or prior to, initiation of improvement programs aimed at developing high-yielding varieties responsive to the items that improved delivery systems will in fact deliver.

We should take note of the fact that in the case of India's Green Revolution in wheat and rice, attention only became focused on the inadequacy of the delivery systems *after* the high-yielding varieties became available. There was little recognition of this fact prior to the Green Revolution period.

The short-run strategy should entail greater emphasis on farming systems research, and breeding for locally adapted improved cultivars resistant to the major pests, diseases, and weeds of the SAT. Rationalizing national price policies in the SAT countries should also contribute to increased sorghum production in the 1980s and must be regarded as part of the strategy.

In India, where HYVs of sorghum have been available for some 15 years, there would seem to be high payoffs to research in the 1980s aimed at understanding and explaining the regional differences in adoption of these "mature" innovations. Has adoption been constrained by deficiencies in the delivery systems in areas where few sorghum growers use HYVs, or are the available HYVs not suitable to these regions? Answers to these questions from the Indian experience will be important in defining R and D strategies in Sub-Saharan Africa. One key issue currently is the relative value and desirability of developing shorter-duration, high-yielding, photoinsensitive cultivars for Sub-Saharan Africa which would be widely adaptable, versus a strategy of improving locally adapted cultivars. Another issue is the relative emphasis which should be given to grain and fodder in breeding programs. In this respect, it appears that there may be less need to consider special-purpose foodgrain cultivars for Africa but rather focus on dual-purpose types; however this may not be so in India.

Increased attention will be required in the 1980s in the SAT to the breeding of sorghum food grain cultivars which are intended for animal feeding. This is because demand for sorghum for animal feeding in developing countries will increase much faster than demand for sorghum as a human food.

In conducting research on sorghum in the SAT during the 1980s, more thought is needed on the appropriate balance between applied and "basic" research, particularly for ICRISAT. To better serve the needs of the various regions of Sub-Saharan Africa, how much of ICRISAT's staff and resources is it necessary to physically locate there vis-a-vis the headquarters location in India, and the emerging ICRISAT Sahelian Center in Niger? This seems to involve a question of balance between "basic" and applied research.

A strong case can be made that a substantial part of research on sorghum at ICRISAT Center in India has direct value to the African SAT and indeed can be more efficiently conducted here. An equally strong case can be made that the pest, disease, agroclimatic, and socioeconomic complexes are so vastly different across the world's SAT regions that "basic" research at one or two centers will be of little value, especially in the 1980s, to the wider mandate area. In addition, particularly in the African SAT. national programs are often unable to effectively utilize such "basic" research due to the lack of human and material resources. In such situations, to be effective, ICRISAT may need to play a more direct role in sorghum R and D. The above issues are complex and will require more concentrated attention in the 1980s.

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Session 8 Socioeconomic Considerations

D. B. Jones* Discussant—2

The papers in this session form an ill-matched team. I think it is significant and not very encouraging that the organizers still believe that conference papers on socioeconomic considerations relate to each other—irrespective of their subjects—rather than to papers on areas of scientific research. To be rather blunt, I think the main value of such a conference is to determine work priorities for ICRISAT, for the national research systems in the SAT, and for cooperating institutions elsewhere, for the decade of the eighties. However, I feel that this purpose has often been only dimly perceived both in the scholarly scientific papers and perhaps most of all in the way scientific research has been tied—or not tied—to socioeconomic considerations. The aim is, ultimately, to feed people.

I also feel, in retrospect, that it was a mistake at this conference to mix up priorities for developed country sorghum producers with those for the less developed SAT. The SAT need the skills of the developed country institutions and experts —there is no doubt about that—but the research priorities of the two types of producers are quite different.

I shall return to these areas, but first I want to comment briefly on the five papers in this session.

Two papers—those by Drs. Busch and Lacy, and Norman—and I might add a third paper by my co-discussant Dr. Ryan, are about overall priorities and strategies. Dr. Arakeri's paper is about socioeconomic issues related to sorghum in India, but can also be used to derive some conclusions on research strategies. The other two papers are ostensibly about more particular problems, but raise interesting issues for research strategy.

David Norman sets out to explain and underline heterogeneity in existing farming systems. arguing from this to different sets of research priorities for India and sub-Saharan Africa. Essentially, his argument, put very tactfully, is that "it is as wrong to ignore socioeconomic sources of heterogeneity (in research) as it would be to ignore climatological-physical conditions"—and by implication that this error is still being made, think this is correct and it raises the important question of the roles of ICRISAT and national systems in ensuring the responsiveness needed. I shall return to this point, but I would remark in passing that although Norman has adopted the India vs Africa generalization merely to make a point and would certainly argue for more sensitive treatment at much smaller geographical scale, the sort of "macro" regional strategic choices he outlines are of relevance in guiding policy for an international research body such as ICRISAT.

I found Busch and Lacy's paper very interesting, but also rather disappointing. As I got into it, I found myself saying "Aha! Now we're really getting somewhere!" At the end I was uncertain whether we really had got anywhere.

The paper opens with a brief analytical survey of research models. The latest and, one presumes, the best, are the "farming systems approach" and the "dialogue" model. I prefer to see these as a single model, and I would regard an approach that restricted its contact with farmers to battering them with questions, and then doing the agricultural research only on a research station, as a rather perverted form of farming systems approach, not its archetype, but I accept the progression given as progress. So far so good.

Now we come on to what is special about sorghum research. This is necessary in order to make prescriptions about what we should do in such research, but I take issue with many of the generalizations here. For instance, we are told that the situation is not like that for wheat or rice. Developing country sorghum farmers are (we are told) even less prosperous than wheat and rice

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farmers. I am not sure that this generalization is true. I think you can find some very large developing country sorghum farmers, and some very small and poor developing country wheat and rice farmers. I suspect that the picture varies greatly by country. Where the generalization is true, it may be because sorghum research has not made the same progress as wheat or maize. The conclusion certainly does *not* follow from the subsequent observation that sorghum tends to be grown on poor soil under rainfed conditions (so, incidentally, does much wheat and rice). We are told that sorghum has small, fragmented markets. This is important, but why is it so? Is it precisely because it is both a very unstandardized crop, and a very difficult crop to process—one might say a "primitive" crop? If so, these are factors that reflect on research, and which research might remedy. Is it difficult to process because processing has not been developed and is not easy for a grain which has very variable characteristics? These links are not filled in. We are told that sorghums suffer local or national price policies that discourage production. If this is true, it is because of price policies for other cereals rather than policies for sorghum. Usually sorghum seems to be an oddball cereal for which there are fewer official policies than, for example, for maize, and this is generally a benefit because official price policies for maize in the lesser developed countries have tended to depress prices to farmers. We are told that there is little history of rich country research to draw on; this is at least partially true, but I think it would be even more valid to argue that rich country (and rich farmer) research on sorghum has tended to be inappropriate and even negative for farmers in the lesser developed countries because sorghum has been developed with different aims under quite different conditions.

Last we come to the actual structure of research, and the process of decision-making in research. While we have some interesting observations here about wrong incentives in national research, about confusion over the division of work between national systems and ICRISAT, and about lack of contact with farmers, we seem to be left (as social scientists often are) making a lot of bright comments, describing the various forces at work, and finally, in place of a conclusion, shaking our heads wisely and saying "It is all very complicated?" I feel this is both too timid and too polite.

Though it is always questionable whether the quality of a research system can be judged by the value of the results (because some problems are tougher to crack than others), I think the lack of progress in developing sorghum as a food crop in the lesser developed countries must raise serious doubts about the health of the international sorghum research system.

Dr. Arakeri's paper is very wide ranging, and is therefore a bit difficult to print down. Some of the points made are not peculiar to sorghum: the need for land consolidation, the need for soil conservation, the need for better arrangements for procurement and stocking of grains. I shall not dwell on these.

The most interesting aspects of Dr. Arakeri's paper to me are a number of apparently isolated statements: the fact that wheat has displaced sorghums and millets from second place after rice in India; the provocative statement "India is a millet country," which is substantiated on climatic grounds; and the very interesting suggestion that better use could be made of scarce irrigation water by diverting it from paddy to sorghum, which is a more efficient user.

Now it is not difficult to see what pushed wheat forward, but what is holding sorghums and millets back? A number of reasons are given: poor extension, lack of appropriate equipment, poor seed supply strategy. These deserve attention. But I suspect the main reason might be that the new sorghum varieties are still unacceptable for human food.

Now I want to turn briefly to the other two papers. First, Drs. Sherman and Ouedraogo on marketing in the West African SAT. The paper exhorts us not to generalize about the West Africa SAT region, but to study each country system in its own particular context. It then goes on to explain that:

(i) all the official cereal marketing boards were set up with similar objectives, i.e., offer "fairer" (better?) prices to producers; reasonably priced supplies to consumers; establish and regulate security stocks; stabilize interyear price fluctuations; organize exports,
(ii) although many of them are legal monopolies, they generally handle only about 20% of *marketed* cereals,
(iii) all have made financial losses.

From these generalizations, I would conclude that there was still some value in generalization. I agree that people who have to make policy decisions on marketing should start off from a good understanding of how marketing actually works in the area in question—and that they often do not do this. Generally, they start from a stereotype that is a priori, ideological, and devoid of factual knowledge. In these circumstances, generalization about what works in comparable conditions elsewhere is a most constructive aid to policy making. For example, the general conclusion that fixed nation-wide prices leave the official board to buy from the most remote surplus areas and sell to the most inaccessible deficit areas has important policy implications. Similarly, the finding that official agencies that set out to handle all the marketed crop seldom handle more than 20% of it should be the subject of serious comparative investigations. Why.is the latter the case? Are the reasons the same in different cases? Is it because (a) the price to producers is too low given the price to consumers? (b) the price to consumers is too high given the price to producers? (c) the organizations are operationally incapable of serving all producers and/or all consumers when they want to trade? (d) do the private marketing channels offer valued services to producers and/or consumers which the official channels do not offer?

The other thing that policy makers ought to take into account in a conscious way is: what are the objectives of their policies? I am somewhat skeptical about the suggestion that all the official authorities had similar objectives. It seems even more clear that the two "factions" mentioned (Harris vs Berg) do not have the same objectives. Objectives are not simple, and involve major trade-offs: e.g., is the objective to develop private entrepreneurs or to eliminate them? Is it more concerned with the purchasing power of peasants than that of urban workers? Is it more concerned about price stability than about operational robustness?

The whole aim of policy-oriented research is to predict what interventions will achieve what objectives in what circumstances, and while this must be founded in knowledge of the systems to be modified, it must also involve intelligent generalizations from situations that involve at least partial parallels. A retreat into careful local studies without generalization is not the answer. Indeed it is a recurrent theme of economics that when we find that theory is letting us down, we retreat into empiricism, only to find that it gets us nowhere.

So far as research strategy is concerned, this paper tends to support Norman's generalization that present conditions in the provision of public sector services to farmers in African countries are not conducive to food production strategies that place heavy reliance on such services; i.e., that a better service/marketing structure must either be part of the package or the package must be robust enough to survive without it. It also carries a fairly simple policy message to governments which think they can run crop marketing.

Lastly, I must comment on Dr. von Oppen and Rao's paper. If I may parody it slightly, it concludes that the unpopularity of high-yielding varieties (HYVs) in India arises from the low monetary value of the associated fodder production which means that the total financial yield of HYVs is only about 6% higher than that of local varieties and therefore "hardly worth" the extra cost of using HYVs. We are not, incidentally, told what those extra costs are. It concludes that it is worth breeding for better straw quality in HYVs.

I found the research and analysis fascinating, but I would qualify the conclusion. The other notable problem with HYVs is the lower price of the grain, which according to this paper sells for only 70% of the price of local varieties. A grain quality improvement that added 10% to the price would add about Rs. 260 to financial yield per hectare. A fodder quality improvement that added 10% to price would increase financial yield by only about Rs. 80-90. If there is any trade-off in resources between breeding for improved grain and breeding for improved fodder, I would suggest concentration on grain. I would, however, agree on the importance of fodder-improving technologies—silage, alkali, early stooking (for green fodder).

Some of the other important questions are also left open. What do people want sorghum for? It is an inconvenient grain to process and to store once processed. Why has its price risen above wheat and rice in Indian markets? I do not know the answer at all, but we do need answers to these questions so as to find out the qualities we are trying to produce.

Another big question is why so little sorghum is marketed. I have put this question to people here and they have answered "because the farmer produces for his own consumption only." This is not an answer; it is a restatement of the situation. Another answer is "the farmer cannot produce in excess of his own requirements." This is certainly true in some areas, but I cannot see why it is particularly true for sorghum and not, for instance, chickpeas. I suspect this has a lot to do with the processing and payability questions. For wheat, rice and some pulses, marketing channels are also processing channels. Thus, for a small increase in price, the purchaser of marketed wheat or maize gets a superior processed product. For sorghum the reverse is the case. There are few economies of scale in processing (partly because of the low value of the bran) and the product is actually inferior to that of home processing.

Now let us get back to the real point. How are socioeconomic factors being taken into account in guiding research on sorghum? The answer seems to be that they are hardly taken into account at all. Do not get me wrong on this. I am not worried about economists and sociologists being short-changed and denied their fair share of jobs. I am worried about misdirected research.

The situation is really not encouraging in either the research or the crop production areas. As Ryan shows, sorghum production is growing slower than population in India and Africa (the overall lesser developed country production figures being distorted by the rapid growth of extensive cattle-feed sorghum in Latin America). Yet, in India, the potential for sorghum is demonstrably high in terms of overall food strategy (Arakeri's paper), and in Africa there is a rapidly deteriorating food situation. HYVs appear to have reached a plateau of acceptability in India—and have hardly made any impact in Africa. That is the situation on the ground.

The situation in sorghum research seems to be exemplified, if not typified by this conference. In Africa, at least, the two biggest problems of sorghum growing are *Striga* and bird pests, yet these were dealt with in only three papers. Quantified economic factors and thresholds were a prominent feature of the papers from U.S. and Australia, but not from ICRISAT, India or Africa. Dr. Frederiksen invited us to quantify disease problems, but did not do so himself. He and other speakers on pests and diseases cataloged fascinating problems and possible approaches to solving them, but did not give any idea of priorities or the most cost-effective ways to search for solutions. Another example, if it is needed, was given by Dr. Frederiksen's statistics on bibliographic references to control of sorghum disease: 31 on host plant resistance, 29 on chemical control, and 7 on cultural control. Yet, for lesser developed country farmers, cultural control is many times more relevant than chemical control. That is one set of problems, and it is a set which I think is eminently in the ICRISAT constituency, and on which social scientists can give useful advice—not off the cuff like this, but by being incorporated into the research planning process.

Another set of problems relates to what the farmer wants and needs. One thing he obviously wants and needs is sorghum that he can process and eat. yet this received almost no attention in the discussion on breeding. I know that ICRISAT has food quality screening procedures, but there is still a serious problem of HYV grain acceptability both in India and Africa. There is no point helping the farmer grow cattle food when he wants to make porridge or beer or bread.

This is just extraordinarily important. Dr. Rooney said "If you have not got yield stability, forget about quality." I think this is almost the wrong way round. In India, HYVs command a 30% lower price on average than local varieties because of this problem. In much of Africa, this problem has almost totally prevented adoption of HYVs. Yet we have gone on breeding for yield and disease resistance (i.e., reliability), and then checking for acceptability. Researchers have to get unhooked from yield if they want people to grow more sorghum in the lesser developed countries. Growing more sorghum is important because it will improve food supply and stability. This is a priority problem common to all the SAT, and one which is susceptible to a centralized research campaign which should have two prongs: incorporating consumer-desired qualities into sorghums with other desired qualities, and tackling the processing questions at a variety of scales. There is a lot to be said for a high-tannin pericarp if the consumer can easily and cheaply take it off when he wants to eat the grain.

Thirdly, there is the question of adaptation to local farming systems. In my view, this is ultimately the job of national research establishments, and must involve use of social scientists at the national level. There is, however, at present a need to service such activity at the regional level. Preferably, this will not be done on the basis of a single center mandate, because farming systems must cover more elements than are ever in a single mandate, including livestock and trees! But there are some signs of a compromise in which individual centers take responsibility for servicing local systems work in particular regions: ICARDA in Middle East. CIMMYT in East Africa, IITA possibly in West Africa, perhaps ICRISAT in this subcontinent. If you do not like this pattern, I suggest you act fast to work on a more satisfactory one.

This will put a new responsibility on the centers for training in farming systems diagnosis and adaptive research. I know that this is urgent in Africa; I suspect it is urgent here.

Further, whatever way this training and servicing function is organized, the centers must seriously and deliberately take on the task of responding to requests for adaptive research inputs from national systems for their particular crops, and this duty must not be confounded with special intensive programs on one or two pet areas by the centers themselves. A particular question this raises is the relevance of hybrids for many areas—especially in Africa—where official systems are not capable of handling timely annual distribution (let alone production) of hybrids.

To sum up, I feel that sorghum in the eighties involves a very serious element of social-economic evaluation, diagnosis, and training, and I do not think this conference has done more than touch on this area in passing. Please do not leave it for Sorghum in the Nineties.

Session 8 Socioeconomic Considerations

Discussion

N. G. P. Rao

Busch and Lacy in their paper have listed four models of research toward generating relevant technology. I would like an additional one called the "innovation" model to be added, where emphasis is on innovation and its diffusion. I would also like to express my disagreement with the often repeated emphasis on generating technological options. In my view, it will be more effective to have a "package approach." Generation and adoption of an integrated package of innovations alone can lead to a rapid transformation of low-yielding and stagnant agriculture.

Norman

The fourth model entitled "dialogue model" in the Busch and Lacy paper is really not a separate model. In fact "dialogue" is an integral component of an upstream approach to farming systems research where technology identification and development effort start from the farmer's field rather than being imposed from the experimental station. Dialogue is an important link between farm and research station.

M. J. Jones

Norman's suggestion about fitting crops to (socioeconomic, natural) environments to ensure relevance of technology in different zones may not bring about a lasting solution in areas like Upper Volta where through soil erosion, falling land productivity, etc., the environment is alreadydegrading. One has to think in terms of both the short- and the long-term context.

Norman

I do not disagree. There are two problems. First, addressing private short-run interests of farmers and record dealing with the long-run societal consequences of an irreversible decline of ecological base. The former required incremental changes with minimal reliance on market system development, e.g., improvements relating to cultivars and their agronomy. The latter requires long-term strategy involving extreme transformation measures to arrest degradation of the resource base. Developmental research and efforts including development of infrastructure is essential to deal with the problem of resource depletion.

Bruggers

None of the four constraints conditioning farming systems suggested by Norman include the vertebrate pests damaging preharvest and postharvest grain. The time required by crop protection (including scaring birds) is enormous. In many areas of the Sahel, the amount of land farmed is determined by the farmer's capacity to protect the crop from birds. How does this problem stand vis a vis the four constraints listed?

Norman

We have delineated four general sets of constraints. The bird damage as a yield-reducing factor and as a source of pressure on labor demand to control it gets into the general set of constraints. The technology or control measure in this context should be one which helps avoid intensive use of labor.

Singhania

Dr. Arakeri's statement about the policy of releasing crop varieties is rather confusing. How can a simultaneous release of hybrids and varieties discourage the seed industry? If varieties or hybrids are good and productive, they should be released. We should bother more about the farmer rather than the seed industry.

Arakeri

My point was that our seed release policy should be consistent regarding varieties or hybrids. We should not waver in supporting one or the other. Our variety release policies can greatly contribute towards the development of the seed industry.

Prasad

Dr. Arakeri mentioned the very limited spread of sorghum hybrids in India. One reason is that the farmers have to buy hybrid sorghum seeds every year in place of using their own seed from the previous harvest. Farmers find this difficult. Seeing this problem, the Tamil Nadu Agricultural University has developed high-yielding varieties of sorghum which have spread considerably (covering 26% of the sorghum area) in the state in recent years.

Rana

A limited spread of high-yielding varieties of sorghum is often attributed to their nonacceptability by the farmers. But adoption of high-yielding hybrid sorghum in Maharashtra State indicated that the farmer is not against it. The real reason for poor adoption in other areas is lack of adequate extension and seed production efforts comparable with those in Maharashtra State. Another reason is the farmers' poor resource position to be able to afford the higher input cost of the package of recommendations for high-yielding sorghum hybrids.

Murty

The price differences between hybrid sorghum and local sorghum in the paper by von Oppen seem to be exaggerated. We have not observed such huge (40-50%) differences in the price of the two varieties.

Prasad

A positive relationship between protein and sorghum grain price does not seem convincing as shown by von Oppen. Price is a function of preference which is often influenced by the color of the grain. For instance in central Tamil Nadu, yellow endosperm sorghum grain fetches a higher price than white grain, in spite of the fact that the former contains less protein.

Dahlberg

Given the need to map out real world distributions and trends, as well as to appreciate the larger content, the following questions emerge:

1. Why was there no assessment of human and animal population and migration trends for the SAT?
2. Why was there no discussion of the risks or possible impacts of regional or global climate changes?
3. Why was there no discussion of deforestation in the SAT as it affects water cycles and regimes?
4. While there was some discussion of increasing energy prices, why was there none on declining water tables, especially in the USA?

The answers may relate to the real operational focus of the symposium—increasing the grain production of sorghum. There is a need to move toward broader and more systems-oriented goals. This would require greater emphasis and work on the following:

1. More emphasis on other uses of the crop (shelter, fencing, fuel, fodder, etc.)
2. More emphasis on multi-year cropping systems and strategies—especially in regard to drought.
3. More emphasis on field-margin interaction and patterns—especially for pest protection.
4. More emphasis on intercropping and diversified farming systems.
5. A more systematic attempt to work directly with the "target" of the symposium—the peasant in all stages of the research, experimentation and delivery.

Session 9

Plenary Session

Chairman: H. R. Arakeri
Co-Chairman: S. Z. Mukuru

Rapporteurs: V. Guiragossian
G. Ejeta

Plenary Session—Recommendations

1. General Recommendations

1.1 National and International Research Programs

The conference recommended the strengthening of national and international research programs on sorghum, with close cooperation between the involved agencies for the purpose of increasing sorghum production. The conference endorsed the concept of Geographical Functional Regions involving a coordinated team of scientists addressing the major problems in these regions. Important components of this concept are the strengthening of communications, technical transfer and training, and the need for improved conditions and facilities for research.

1.2 Training

Training is essential in every aspect of agricultural development; the training of scientists across the whole spectrum of disciplines is important. These include plant breeding, germplasm manipulation, plant protection food quality, crop relationships, environmental interaction, production of quality seed, extension, and marketing. Emphasis should be placed on training administrators in areas of policy and experiment station management. Types of training should include degree, technical support, special techniques, and refresher courses.

1.3 Sorghum in the Nineties

The conference recommended that a third international symposium be held in 10 years' time to review the progress made in the 1980s and make recommendations and set goals for the 1990s.

2. Factors Limiting Sorghum Production

2.1 Environmental Stress

Although certain factors, particularly drought, were emphasized as being of major general importance in limiting sorghum production, it was clear that the most important environmental constraints differ between regions. Seedling emergence, high or low temperatures, and soil factors such as nutrient deficiencies or toxicities are constraints of major importance at certain sites. Furthermore, seasonal patterns of climate, particularly of water availability, are crucial in determining optimal plant type and management strategies.

Because of the complexity of the processes which affect yield, there was a general consensus that effort should be devoted to improving experiments and physiological understanding in order that reliable predictions for different environments can be made. This is equally important for both soil and climate constraints and implies the development and use of appropriate mathematical models. Sorghum yield improvement in the 1980s will involve parallel advances in agronomic techniques and breeding methods.

2.1.1 Need for a clear definition of environment,. its variations between and within seasons, and of the yield-limiting factors at each site. It is important to identify the relative probabilities of occurrence of different types of stress.

2.12 Increasing the input of crop physiology into management and breeding programs for environmental constraints. This requires increased emphasis on the training of workers in physiological techniques both at universities and in practical training programs (e.g., at ICRISAT). Lack of personnel, facilities, and funds for physiological work, especially in developing countries, is a major constraint to sorghum yield improvement.

2.13 Major advances in sorghum improvement requires the creation of multi-disciplinary teams with breeders, physiologists, agronomists, climatologists, etc. These would be best concentrated at a few centers (e.g., ICRISAT).

2.1.4 Need for improved information services to collate and index data from past and future sorghum experiments. These would also be best coordinated at one center.

2.1.5 Need for a minimum data set to be collected and reported in all experiments that would include measures of environment, soil factors, farming systems and crop phenology.

2.1.6 More basic physiological research in crop and stress physiology is essential for longer-term advances. This may be achieved effectively in relation to sorghum in the SAT by encouraging contract research.

2.1.7 More exchange programs and conferences would facilitate rapid information transfer.

2.1.8 There is a need for the development of improved diagnostic techniques for nutrient deficiencies or excesses. An institute —perhaps ICRISAT—should prepare an appropriate handbook.

2.1.9 The development of simple, reliable, and rapid screening techniques that would be suitable for use in early segregating generations is urgently required. However, more effort needs to be concentrated on validating each stress situation before they are too widely applied. The identification and validation of appropriate characters will be achieved best by the full-time participation, with physiologists and agronomists, of a breeder released from the constraints of variety production.

2.1.10 Studies on root physiology of sorghum should be increased in view of its importance in nutrient and water uptake. There should also be some emphasis on biological nitrogen fixation.

2.1.11 Recognizing the large gaps between research station and farm yields, an increased effort in farm-level research is needed in the 1980s.

2.2 Pests

2.2.1 Pest surveys should be continued, utilizing simple and effective sampling techniques to determine both preharvest and postharvest crop losses in order to progress toward the development of genuinely integrated pest management practices and to minimize reliance on strictly prophylactic pest contol. Economic thresholds must be established for pest and pest complexes to assist in making insect control and crop management decisions.

2.2.2 Emphasize research on basic aspects of pest and beneficial arthropod biology, ecology, behavior, and population dynamics for use in pest forecasting and systems modeling, and in developing effective and practical integrated pest management strategies applicable to cropping systems in both developing and developed countries.

2.2.3 Continue efforts toward protecting sorghum from arthropod depredations by breeding plants resistant to pests and/or damage. Develop effective programs for measuring plant resistance to multiple pest species, including efficient and reliable techniques utilizing artificially-reared insects to screen cultivars under controlled insect pressure and environment. Utilize international pest nurseries to locate broad-spectrum and stable sources of resistance and to identify insect biotypes. Determine mechanisms and inheritance of resistance to specific pests.

2.2.4 Initiate significant research efforts in areas of biological control through the utilization of efficacious natural enemies by their conservation, importation, and/or augmentation. Every effort should be made to integrate pest control strategies including the use of: efficacious natural enemies, sorghum varieties with pest-resistant characters, cropping practices unfavorable to the pest, and the judicious use of selective pesticides.

2.3 Diseases

2.3.1 A comprehensive account of the major and potential diseases on a global basis with specific recommendations on the future strategies for disease management is available in the published proceedings of the 1978 ICRISAT International Workshop on Sorghum Diseases. The priorities identified at that workshop need to be followed effectively in the 1980s.

2.3.2 We recommend intensive surveys and the monitoring of major diseases on country and regional bases, and the assessment of crop losses in the 1980s.

2.4 *Striga*

2.4.1 Present research efforts to develop effective systems of *Striga* control and the implementation of control measures are totally inadequate for the current task. We recommend that donor agencies set up a small advisory group to study the problem and to prepare proposals for a greatly increased research effort on *Striga.*

2.4.2 Although some progress has been made in the identification of resistant cultivars, there is a need to develop simple and reliable field-screening techniques, and to understand the various resistance mechanisms.

2.4.3 Other aspects requiring attention include: the mechanism by which nitrogen and drought stress influence *Striga* attack, particularly in the more resistant varieties; better understanding of the pattern of *Striga* seed germination under field conditions and the reasons for reduced emergence under wet and/or shaded conditions; the potential for biological control; the potential for artificial stimulation by ethylene and synthetic stimulants; the potential for induction of resistance by seed hardening with phenolic acids; techniques for direct assessment of yield loss (as a means of assessing performance of resistant lines and of generating crop loss data).

2.5 Birds

2.5.1 We recommend to donor agencies that they should continue to support and encourage (a) research into the biology, movements, and control of *Quelea* and other bird pests in Africa, and (b) the transfer of the technology to government organizations through the training of plant protection personnel to take advantage of the progress achieved in recent years. Similar programs should be initiated where birds also severely damage sorghum and millet grain.

2.5.2 In most situations in Africa, control of *Quelea* through a program of total population reduction is extremely unlikely to succeed because of the high reproductive potential of the species and the vast inaccessible areas in which the birds are distributed and because *Quelea,* like all the major bird pests, are highly visible migrants and opportunistic feeders. For practical, economical, logical, and environmental reasons, we recommend and support the premise that lethal control should be directed only to those birds actually causing damage or whose movement patterns will take them into susceptible cropping areas.

2.5.3 We recommend that additional strategies such as chemical repellents, barriers, cultural and agronomic methods, and genetic deterrent characteristics in the plant itself continue to be evaluated so that safe, economical, and effective control techniques are available for use in appropriate situations, either alone or in combination with lethal measures.

3. Genetic Resources

3.1 The task of germplasm resources units in the 1980s is enormous. During the 1970s a working collection of sorghum germplasm was assembled from across the range of *Sorghum bicolor* (L.) Moench. Collections were classified and methods were devised to maintain these sources. Demands during the 1980s are going to be for the more efficient use of the assembled germplasm. New sources of resistance to diseases and pests were identified in landraces, and other collections proved to be of such superior quality that they were directly incorporated into breeding projects in countries far beyond their origins.

3.2 Quality of germplasm has become more important than the number of collections in gene banks. Collecting remains an important task of genetic resources units. But collecting efforts must be concentrated in those areas where landraces are in danger of extinction, and in habitats where genotypes of particular value to breeders are expected to be found. The number of collections, and range of variation of the close wild and weedy relatives of sorghum also need to be increased. Wild species taxa retain variation that was lost in grain sorghum during the process of domestication.

3.3 Sorghum descriptors were standardized during the 1970s, and facilitate worldwide communication among breeders and keepers of germplasm. This does not mean that descriptor lists may not be revised. New information from breeders and other scientists working with collections must continuously be added to the data bank. For future collections a greater effort must be made to record more information at the time of collecting. Traditional farmers are experienced plant breeders, and usually can provide important information on adaptation to soil and climate, disease and pest resistance, uses, and the nutritive value of the cultivars that they grow. Such information is of vital importance in germplasm banks. Efforts to computerize all germplasm data must continue. Computer-assisted retrieval systems are prerequisites for the efficient operation of genetic resources units.

3.4 The value of the sorghum gene bank can be fully realized only when collections and selected genotypes are available in packages useful to breeders. Collections must be screened for agronomically useful traits, wherever possible in collaboration with breeders, entomologists, pathologists, physiologists and other interested scientists, as soon as possible after they enter gene banks. Genotypes of significance must continuously be sorted out, and preserved separately from the parent collection. The need is also going to increase for pools of genotypes and collections with known resistance to disease and insects, drought tolerance, exceptional grain qualities, high yield under diverse environmental conditions, and adaptation to specific geographic and climatic regions. Such populations can serve as immediate sources of desirable gene complexes in breeding projects.

3.5 Conversion projects must be expanded and accelerated. Tropical lines converted for use in the temperate zone must be incorporated in gene banks for use in the tropics. Selected genotypes must also be incorporated into conventional African and Indian breeding lines, and the significance of wild germplasm in breeding projects must be explored.

3.6 Mechanisms for the efficient exchange of germplasm must be established. It is essential that outstanding collections be evaluated and maintained in regional locations in Africa, the Americas, and at ICRISAT. This will encourage wider use of this germplasm across a broad area of sorghum cultivation. It will also provide an added degree of safety to the conservation of valuable germplasm.

3.7 ICRISAT must be commended for its foresight in the 1970s in establishing a genetic resources unit. This, in our view, was an essential step to ensure the timely collection, conservation, and utilization of the rapidly vanishing sorghum germplasm. The current efforts and activities of this unit are exceptional. With imaginative use of the assembled and still-to-be-collected germplasm, sorghum improvement during the 1980s will be enhanced.

4. Genetics and Breeding

4.1 Development of superior varieties and hybrids has occurred over a long period of time. Interest is increasing to help subsistence farmers living in harsh environmental conditions. The contribution of resistance traits and heterosis to stability is important, particularly to subsistence farmers, and continues to need further evaluation and application.

4.2 The germplasm base in most traditional farming areas is quite narrow, restricting gains from selection. The usefulness of introduction as a means of germplasm diversification is widely recognized. The contribution of local varieties to adaptation is also recognized. Crossing between local varieties and selected high-yielding introductions is a valuable approach to developing well-adapted varieties and hybrids that respond to management inputs. It should be recognized that useful varieties and hybrids developed from introduced materials may also contribute to high yield and stability. This approach has been and should be further exploited.

4.3 Traditional breeding methods and population methods using recurrent selection are complementary, and both should be employed. An interacting international network for population breeding should be developed. Evaluation of population breeding procedures for different criteria should be undertaken.

4.4 The understanding of apomixis in sorghum has improved; the potential practical exploitation of apomixis in the vegetative production of hybrid seed needs to be established. Further studies of cytoplasm-genome interaction as related to genetic vulnerability are required.

4.5 The important factors reducing yield are widely recognized. Most of these problems are severe in relatively broad geographic regions. Their solution in part rests on an understanding of the mechanisms of resistance and how these are inherited. Greater understanding of these factors for almost all important traits is required in the 1980s.

4.6 A minimum data set, including climatological parameters, cultivars used, planting and harvest dates, fertilizer application, etc., should be accumulated as part of yield trial and screening nursery activities to facilitate better interpretation of research data.

4.7 There is need to better understand the physiological basis of "adaptation", and how this can be translated into practical production.

5. Production Technology

5.1 Much has been learned about intercropping, multiple cropping, and relay cropping during the 1970s. These techniques are commonly associated with subsistence agriculture in an effort to reduce risk; but they are also employed, to a more limited extent, where high yields are recovered from responsive varieties in high-input situations. The indentification of high-yielding varieties and hybrids selected to fit different crop relationships and management inputs, for higher yield returns than are currently being realized, should be evaluated in a range of sorghum-growing environments in the 1980s.

5.2 In Africa, and elsewhere, as pressure on land use increases, soil fertility is being reduced. Therefore, to increase yields, soil fertility will need to be maintained and enhanced, particularly by using locally available materials such as lime, straw, ash, rock phosphate, and animal manure. The use of these inputs, as well as other management inputs achievable by subsistence farmers on small holdings, need research emphasis during the 1980s.

5.3 The use of good cultural techniques, i.e., seedbed preparation, mechanical sowing, and weeding, are essential to obtain good results. Attention has been directed to animal-drawn implements. Research on such equipment and on the modification of simpler tools currently used by farmers to better adapt them to local conditions and to offer farmers a greater choice of diverse equipment should continue. Attention shoud be paid to the use of motorized equipment where relevant. The use of farm mechanization in areas of intensive labor use should be carefully evaluated for long-term possibilities in the creation of job opportunities.

5.4 Attention was focused on postharvest grain losses, which represent about 10% of sorghum production. Many centers appear to be carrying out research on postharvest technology. However, there is room for more research, particularly to refine and improve traditional methods.

5.5 There is a need to effectively recognize quality seed as an important component in agricultural development. The production and marketing of seeds with quality control has many aspects involving both private and government contributions. As the commercial use of F_1 hybrids becomes possible, it is extremely important that the relevant authority in a country takes the time to study the seed industry in those countries where it is established in order to obtain data on it as a guide in developing their own system. Relegating the production and marketing of seed to a department of agriculture or an extension service will almost certainly result in failure to have adequate quantities of quality seed in the right place at the right time for the farmer.

5.6 Interest is increasing in the growing of sorghum in new areas: for example, in areas marginal for maize; sorghum following rice; sorghum on low-pH soils where aluminum toxicity is a problem; and the possibilities of ratooning, particularly in areas with bimodal rainfall. Sorghum in these situations can contribute usefully to increased food production, and such development should be encouraged.

5.7 Beside concern for improving production practices on farmer's fields, there is a recognized need to develop a better understanding of and the capability for developing and managing experiment stations. It is recommended that educational and training institutions be encouraged to take a more active interest in this area.

6. Food Quality and Utilization

6.1 It is imperative that governments in developing SAT countries implement a plan for the production of locally-adapted food crops to be increased so that importation of food grains would not be needed. At present there are countries in the sorghum-growing areas of the SAT that have to import large quantities of other food grains annually in order to feed the population in rapidly growing urban areas and in rural areas struck by drought and hunger. Special attention should be given to pricing policies regarding locally-produced and imported cereals so that there is an incentive for the farmer to produce sorghum as a cash crop.

6.2 It is fundamental to document sorghum food preparation practices, including decortication, milling, and cooking in areas where sorghum is traditionally eaten. It has recently been shown that several of these techniques improve not only the acceptability but also the digestibility and nutritional quality of sorghum grain. Laboratory evaluation methods of the main sorghum foods should be standardized and financial support be given to laboratories working with the following food systems: *td* (thick porridge), to be located in West Africa; *kisra* and *injera* (fermented breads), to be located in Central America; and rice-like products and noodles. These laboratories should be provided so that they can work efficiently as regional service centers for breeding programs. Adequate support should be given for studies on the fundamental food technology properties of sorghum, involving milling and cooking, and their relation to seed quality.

6.3 Documentation of the present sorghum food-eating habits is required in relation to the crop's nutritional status. Studies in traditional sorghum-eating areas to document the composition of the integrated food in relation to nutritional status should give the basis for further studies with experimental animals and humans so that we can better understand how sorghum is best utilized as a food.

6.4 Development of the nutritional quality of sorghum is essential. Studies on the sorghum tannins and polyphenols, which might be agronomically desirable but which are detrimental to digestion and protein utilization, must be intensified. Their chemical identification, physiological role, and methods for their removal by extraction, alkaline treatment, and decortication must be considered. Protein quality improvement in sorghum grain should continue as a research objective using all available germplasm, with special emphasis on yield stability and food-grain quality. Studies on sorghum protein and energy availability with in vitro and in vivo methods should be intensified with special emphasis on its relation to the structure and chemical composition of the seed, and on its relation to human nutrition.

6.5 New developments in sorghum food processing are required. To relieve the hard work of hand-decortication in rural areas, it is essential that suitable village-scale decortication and milling techniques be developed and efficiently introduced in areas where sorghum is decorticated. If sorghum is going to compete with maize and wheat in the urban areas, there is a need for efficient industrial mills that can produce a white flour of the available sorghum varieties with a milling yield of not less than 80%. Convenient, attractive, and nutritious foods from sorghum with an improved shelf-life must be urgently developed and marketed.

6.6 The development of the industrial uses of sorghum—for example, malt, brewers grits, starch, fiber (for paper and building board), ethanol (for fuel) and feed—should be actively stimulated to make developing SAT countries more self-sufficient in these commodities. Emphasis should be given to investigate the feasibility of integrated systems featuring whole-plant cropping, e.g., sweet sorghums producing food, feed, fiber, and fuel.

7. Socioeconomic Considerations

7.1 There is need for closer collaboration between biological and socioeconomic researchers to address such problems as the following:

7.1.1 Evaluation of sorghum improvement not only as yield per hectare but also as returns per unit of labor, particularly at peak labor-demand period.

7.1.2 To examine the differential impact of cereal grain procurement policies on sorghum production and distribution.

7.1.3 To explore ways to work with national governments to assist in evolving policies that will support and encourage new technology.

7.1.4 To evaluate market value for uses of sorghum as feed, construction, and fuel in relation to grain so that properly balanced crop improvement objectives can be defined.

7.2 Based on socioeconomic criteria, it is desirable to place higher research priority on countries in Africa than in the past. A two-pronged strategy is recommended: a short-run strategy with emphasis on incremental change using high-yielding varieties and hybrids with inputs, and a long-range strategy to increase production in environmentally harsher conditions where low soil fertility and erosion are problems.

7.3 It is recommended that researchers should develop a range of technological options rather than inflexible packages for farmers. As far as possible, adaptive research should be carried out in farmers' fields. The actual situation, resources, and methodologies of the farmer should be fully understood and modifications and improvements should be tried with the farmer. Their value should be assessed at each stage; other experiment station programs should be started with the object of enhancing the farmer's current status.

Valedictory Speech

A. H. Bunting*

Mr. Chairman, colleagues, and friends,

On behalf of all members of this Symposium, as well as on my own behalf, I want to thank the sponsors, ICRISAT, INTSORMIL, and the Indian Council of Agricultural Research, for providing this Symposium, and for making it possible for us to attend, to learn so much, to meet each other, and to exchange our opinions and experiences. I want also to thank the organizers and others who have helped to make this so splendid an occasion. I think here not only of the many people who are named in our program, including the chairmen, the co-chairmen and the rapporteurs, but also of the many others who are not named, including the translators, the secretarial and the office staff, the canteen workers and the bus drivers, who have worked long hours to serve us, without complaint and indeed with enthusiasm. I would like you to join with me in expressing to them our warmest thanks for all they have done.

We shall all remember with pleasure the many evidences of productive cooperation between ICRISAT, Texas A&M University and the Pioneer Seed Company. No doubt these close and harmonious relationships would give special delight to Mr. Pat Mooney, the author of "Seeds of the Earth." Nevertheless, I cannot but applaud the principle and the benefits of close cooperation between an international center, a university in a developed country, and a distinguished and reputable seed and plant breeding company in the private sector, which is moreover providing an essential service in the developing world. I was happy too to feel that what is being done here benefits not only the human consumers of sorghum in the developing countries but also the steers, cows and other animals of Texas and neighboring states, and those who eat their products.

Now we have been talking about sorghum in the eighties. The most important thing about the eighties is that they lead to the nineties, and the nineties end with the year 2000. Research done in the seventies, and maybe some that we shall do in the eighties, may come to be applied on a sufficient scale in practice to allow development to proceed more rapidly in the coming 20 years than it has done in the past 10. Perhaps it will even help to reverse the current adverse trends in Africa.

But there are many effects and trade-offs in development between sorghum and other crops, particularly the giants, wheat, maize and rice. All dedicated workers on a single crop naturally seek to advance it in any way they can. Nonetheless, I think we have to be realistic about the way in which the world's food needs are likely to evolve. We must ask ourselves, soberly, how much sorghum the world will in fact require in the year 2000, where it will require it. and what kinds it will require. And with the answers to these questions we must adjust our research in such a way as to help mankind to achieve those specific and quantitative development objectives. The sky cannot be the limit for this crop.

Research and knowledge are far from the only inputs needed for such a development in the critical 20 years ahead. The volume of effective demand will determine the quantity of sorghum that will be required by the market. There are many weaknesses in the output delivery systems, such as physical infrastructure, transport, markets, storage, processing, wholesaling and retailing, and prices. These components determine the extent to which farmers can sell off the farm, which is the essential nexus in the whole business of agricultural and rural development. But farmers, in doing this, have to work, as we have heard, with limited resources which are restricted

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru, A.P., India. Patancheru, A.P. India: ICRISAT.

in different ways in different places and at different times. And the resources they can allocate to agricultural production are also required for other sectors of their life systems. Consequently, a very complicated story indeed lies between new knowledge, the product of research, and increased output and consumption at the end of the day.

The resources of farmers are not confined, let us remind ourselves, to the classical factors of land, labor and capital, although by suitable definitions we can fit all resources into one or other of those omnibus packages. We have to think also of seed, equipment, knowledge, chemicals, credit and many other things, as well as of external encouragement, services and support, particularly from the policy of governments. Development in Africa might well take a different course if governments were able to be more effective. Many African governments and government services are inexperienced and some are unstable. Many of them have great difficulty in forming and executing development plans.

Technically, there is nothing basically wrong with Africa, except perhaps in the most arid regions. All of us here know about the substantial progress which Kenya has been able to make, and I have recently had the very pleasant experience of seeing the remarkable progress made in Zimbabwe. By increasing the price of maize to farmers from 75 to 120 Zimbabwe dollars per tonne, Zimbabwe has harvested for herself in one year, admittedly a favorable one climatically, over a million tons of maize more than she requires for internal consumption or use. The job can be done technically in many countries of Africa, but the problems about doing it are mostly not at the research end. Incomplete as it is, we already have knowledge enough in Africa to do a great deal better than we are doing now. The negative trends in Africa are not solely due to lack of knowledge. We shall claim too much if we say "give us money, we will do research, and we will solve the African food problem."

Research does not address itself, or listen, to farmers alone. It has many other clients besides growers. It has to speak to governments, civil servants, development agencies, and the suppliers of equipment and inputs and the sellers of outputs. The research worker has to address himself, and listen, to all these people. Hence, all models which have no more than research on one side and the farmer on the other are unduly simple. They represent an unduly limited conception of the functions of knowledge in agricultural change and development, particularly in the poorer countries, they are not even appropriate in the developed countries, even though so many of the constraints on change in them have been managed that knowledge may indeed become a major limiting factor to progress.

All these features vary enormously in different parts of the very extensive and scattered domains where sorghum is grown. Sorghum scientists need to be aware of the diverse objectives, potentials, constraints and alternative opportunities of sorghum growers in these many and diverse domains, and they have to arrange their goals and priorities in research accordingly. Since they tend to be locale-specific, there can be no one single, or simple, set of goals and objectives. I believe therefore that it is very important that ICRISAT should continue its efforts to understand comprehensively the true nature of the sorghum production and demand problems in the different territories of the earth in which sorghum is now important or might become important in the future.

Much information relevant to this comes from the existing practices of growers, for whom I personally have the very highest respect. In 1891, after his 2-year visit to India, A. J. Voelcker wrote:

> "Practical enquiry, or the obtaining of knowledge respecting agricultural practice, precedes both scientific enquiry and experiment. The scientist, without some knowledge of the practical issues involved, is unable to push his enquiries in the right direction, and however able his research is, he may fail from being unpractical. Similarly the experimenter, without a knowledge of what is done elsewhere, or what is within the reach of the cultivator, may waste both time and money in trying what has no chance of ever becoming of any practical value.
>
> "The practical man must first become thoroughly conversant with what is being done in native agriculture, and with the conditions under which it is carried on. Then the scientist may come in and explain the rationale of the practice and may apply these principles to the extension of the better systems and to the discovery of further resources. Finally by the happy combination of science and practice the work of experiment may proceed in a definite and useful direction. In this way, some advance

in agriculture may be made.

"I believe that it will be possible, here and there, to graft on to native practice the results of western experience, but the main advance will come from an enquiry into native agriculture and from the extension of the better indigenous methods to parts where they are not known or employed."

Colleagues, that was written 90 years ago.

I want to illustrate the principle by some examples from northern Nigeria. I am aware that not everyone here will agree with what I am going to say, but I am going to say it nevertheless. Since I believe it. I must be content to differ from those who do not feel the same way as I do.

In northern Nigeria, the work of Curtis (1968) indicates that photoperiod or lack of response to photoperiod is an absolute determinant of the type of sorghum that can be most successfully grown in a particular region. Moreover, response to photoperiod, or lack of it, determines not only what can or cannot be done with sorghum, it determines the place of various kinds of bulrush millet in the farming systems and the nature of the intercropping practices which involve cowpeas (see Bunting 1975). The reason for this seems quite straightforward. It is that in northern Nigeria the onset of the rains is unpredictable, whereas the termination of the rains is much more predictable. It is possible therefore to use photoperiod sensitivity, or lack of it, to time a whole series of agronomic events in such a way that the outcome carries minimum risk and maximum likelihood of benefit to the cultivator. There is no way of achieving this by using other types of adaptation.

I am not attracted by the easy set of words that so many of us use—"short-statured, early-maturing, photoperiod-insensitive, widely-adapted types." This is derived, in part, from the practice of temperate agriculture, where indeed we do need such types, each adapted to its own conditions, in order to secure ourselves against the risks of summer drought. But when we start applying these concepts to tropical conditions, particularly when we have imposed them on our research program as a consequence of the conversion program in sorghum, we may meet substantial difficulties. If flowering and maturity come too early, we may substantially increase damage by insects and fungi, so that we have to increase resistance to head rots. If we get it wrong the other way, we run into dry weather. and therefore have to step up our research on adaptation to drought. No doubt both these sorts of research are useful, but the risks would be minimized if the time adaptation were right. It is like shooting yourself in the foot and then calling for a pair of crutches and a bath chair. It is far better not to shoot yourself in the foot in the first place.

All this arises from a point that I made earlier in this meeting. All too few of the scientists who come for the first time to work in the tropics are aware of the fundamental differences between tropical and temperate environments in water regime and nitrogen cycling let alone the differences in social and economic settings. This has led, in my view, to substantial wastage of resources in tropical agricultural research.

Now I want to turn to plant breeding. I am not a breeder and what I say may therefore be wrong as well as subversive. We have evidently to improve our crop in respect of a wide range of multiple objectives—not merely potential "high" yield, important as that is. We have heard about nutritional attributes, resistance to storage pests, local adaptation to environmental circumstances, diseases, pests, quality for the consumer and many other things. Breeders are bound, in my view, to keep all of these objectives constantly in view. It may be difficult to select or breed. for them all at once; but we shall remember that if we do not positively breed for a character we are likely to breed against it. Nor must we fragment the process unduly, for example, by asking different breeders to breed separately for different objectives.

We may take encouragement from the way in which, since the early days of IR5 and IR8. our colleagues at IRRI in the Philippines have now got up to IR54. In that range they can offer various types of plant structure appropriate for large yields in different environments, with various culinary qualities and an increasing range of multiple inbuilt resistances to pests and diseases.

Let me add an even cruder example. That giant of plant breeding and genetics, S. C. Harland (1949) transformed Tanguis, the main cotton of Peru, by what he named the mass pedigree system of selection. By setting standards for six characters which could be measured on single plants, rejecting plants or small bulks in which these characters were below the norm or the arithmetic mean, and by advancing the standards in successive years, he soon produced populations of improved quality which yielded very much more than before. Starting from preliminary observations, in 1940, the first wave of about 500 000 kg of improved seed was issued in 1943; and by 1949 yields around 1 tonne of lint per hectare were being harvested on a field scale by some farmers. In respect of characters other than those for which they had been selected, the new populations were genetically heterogeneous and further improvement in them was evidently feasible.

I am sure that breeding for multiple objectives is essential if we are to attain our objectives sufficiently rapidly to benefit hundreds of millions of farmers and consumers by the year 2000. If the hybrid route can rapidly achieve the necessary multiple objectives on such a scale that millions of growers in different environments can benefit from it within the coming 20 years, well and good; but I would urge that this matter be very carefully considered, particularly in relation to the role of the seed and breeding industries.

Seed and breeding industries are obviously of central importance to us. I separate the two deliberately. The first requirement may well be a seed industry to meet the demand of farmers for good, clean seed of suitable type at an acceptable cost. The breeding industry may then come along at a later stage. Perhaps it is in this area that the big difference lies, in international agricultural research, between the substantial and increasing effect on output and on yield per hectare in wheat and rice, and the very much smaller global effect on maize. I believe that we would do well to consider how it comes about that very dedicated and devoted international research on maize, against the background of science and practice which has made maize in the United States the highest yielding cereal in the world, with an average, across all maize growers, of 6.86 metric tons to the hectare on 29 million hectares in 1979, has not had anything like the effect that the international work has had in wheat and rice. I suggest that this has to do with the breeding system and with the problems of seed industries and breeding industries. In sorghum, which is sufficiently out-crossed to run into similar problems, we may well need to adjust our breeding procedures and our recommendations to the real facts of life in respect of the development of the seed and plant breeding industries.

We have now reached the end of this very rewarding symposium. At this point we say to each other, to our generous and kindly hosts, and to this splendid institution, au revoir, a la prochaine fois—goodbye for now, until we meet again. We all look forward to many meetings in the coming 10 years, to the flowering of new friendships and new collaborations. From the heterosis which these associations will generate I believe we shall harvest record yields of new and relevant knowledge and understanding with which to advance the progress of all who grow, and all who use, the sorghum crop and its products worldwide.

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Appendix 1
Short Communications

Short Communications

Climate-Yield Relationship in Traditional and Improved Sorghum Cultivars in India During the Past Decade

B. B. Redely, M. V. K. Sivakumar, V. Jaya Mohan Rao, K. Vidya Sagar Rao, and N. G. P. Rao

Abstract

Consequent to the climatic vulnerability of traditional Indian sorghums, new cultivars with altered plant type, duration, dry matter production and growth rhythms have been developed and cultivated commercially.

Soil, rainfall and evapotranspiration, and yield data are available from several diverse locations during both *kharif* (monsoon) and *rabi* (winter) seasons over the past decade, when normal, subnormal, and above normal rainfall situations were encountered.

A comprehensive analysis of the climatic factors, yield and their interrelationships during the decade of the seventies is attempted. Both sole crop and cropping system yields have been considered. The implications of this analysis on dryland sorghum improvement will be analyzed.

Photosynthetic Characteristics in Relation to Dry Matter Accumulation in Sorghum Hybrids and Their Parents

Renu Khanna Chopra and S. K. Sinha

Abstract

Heterotic sorghum hybrids CSH-2, CSH-3 and the their parents were analyzed for leaf area, photosynthesis rate and activity of photosynthetic enzymes during growth and development. RuBP carboxylase and PEP carboxylase were examined in panicle components also, during grain development. Dry matter production was greater in hybrids compared with their parents. Hybrid CSH-3 accumulated more dry matter before anthesis while CSH-2 accumulated more dry matter during grain development. Photosynthesis rate, RuBP and PEP carboxylase activity in the leaves was similar in inbreds and hybrids. Compared with leaves, the panicle had a lower activity of photosynthetic enzymes. Heterosis was not observed in the activity of photosynthetic enzymes in the panicle. The above results will be discussed to explain the higher dry matter production and yield in heterotic hybrids. Significance of dry matter accumulation before and after anthesis will also be considered in relation to adaptability.

Influence of Rainfall on Grain and Stover Sorghum Yields

Mario da Andrada Lira

Abstract

A study was conducted aiming at the determination of the influence of rainfall on grain and stover sorghum yields. The study was carried out without any supplementary irrigation. It included nine environments and three varieties in each of two locations of semi-arid Pernambuco, Brazil.

Results indicated that stover yield was highly significant and correlated with total rainfall during the crop cycle. For each mm of rainfall, stover yield increased 23.7 kg/ha. There was no clear response to rainfall for grain yield. In one of the locations, grain yield was significantly correlated with rainfall in the first 60 days after planting, as well as with rainfall from the 40th to the 70th day of the crop cycle. For the other location, the correlations were generally not significant. For each mm of rainfall from the 40th to the 70th day after seeding, grain yield increased from 10 to 52 kg/ha.

Screening Sorghum Genotypes for Tolerances to Mineral Element Deficiencies and Toxicities

R. B. Clark, P. R. Furlani, G. E. deFranca, A. M. Furlani and Y. Yusuf

Abstract

Plants that can tolerate and grow well under mineral element deficiency and toxicity conditions need to be identified and developed, so that they can be grown successfully on marginal lands and with fewer or limited fertilizer/soil amendment inputs. A relatively simple and inexpensive method for screening sorghum genotypes for tolerance to mineral element deficiencies and toxicities in nutrient solutions was developed. This method has been used successfully to screen sorghum (*Sorghum bicolor* [L.] Moench) genotypes for differences in tolerance to low levels of N, P, and Fe, and to toxic levels of Al. The method consists essentially of growing a fairly large number of plants (60-125) in the same container with relatively low volumes (50-100 ml/plant) of nutrient solution containing limited amounts of the element of concern or with added elements/compounds to induce a deficiency or toxicity. Conditions that gave wide differences among genotypes for low N, P, and Fe and to toxic Al were: N—10 mg N/plant as NO_3 + NH_4 + (8:1); P—64 µmol/1 (2 mg) as KH_2 PO_4, calcium tribasic phosphate, or ethylammonium phosphate; Fe—deficiency induced by adding high P or by using NO_3^- only as a source of N (to raise solution pH); and Al—148 µmol Al/l (4 mg) with 64 µmol P/l.

Rapid Screening of Sorghum Seedlings for Tolerance to Low pH and Aluminum

Canldo Bastos and Lynn Gourley

Abstract

A rapid screening procedure for evaluating sorghum, *Sorghum bicolor* (L.) Moench, seedlings for tolerance to aluminum (222 µM) at low pH (4.0) using a modified Steinburg nutrient solution is described. The parameter measured is the rate of seminal root elongation observed after a 6-day treatment period. Seeds were germinated and transferred to the treatment nutrient solutions after 3 days. Twenty-seven of 158 genotypes were found to equal or exceed the laboratory tolerance level of SC-175-14(IS-12666C), a genotype with good tolerance to low pH-high aluminum soils. Genetic studies and additional screenings of lines from the World Collection of sorghum are under way. All genotypes tolerant to low pH and aluminum will be screened for tolerance to manganese in nutrient solution and field evaluated in soils of pH 4.0 with an aluminum saturation greater than 64% of the C.E.C.

Aspects of Nitrogen Fertilization of Sorghum

J. T. Moraghan, T. J. Rego and Sardar Singh

Abstract

Nitrogen deficiency is a constraint to high sorghum yields in India. Soil nitrogen dynamics in the region are complex. Four separate situations are considered: (a) *kharif* production on Vertisols; (b) *kharif* production on Alfisols; (c) *rabi* production on Vertisols after a *kharif* fallow; and (d) *rabi* production on Vertisols after a *kharif* crop. Denitrification and nitrate leaching losses are likely problems in (a) and (b), respectively. Split applications of banded nitrogen fertilizer under high rainfall conditions have increased fertilizer efficiency in (a) and (b). Positional availability of fertilizer, due to dry soil zones, is a possible constraint in (c) and (d). Deep placement of fertilizer is needed in such situations. Pertinent research involving the isotope N^{16} and soil nitrogen mineralization will be discussed.

Insect Pests of Sorghum in West Africa

K. F. Nwanze

Abstract

Three species of insect pests are considered important in West Africa: the shoot fly, mainly *Atherigona soccata:* sorghum midge, *Contarinia sorghicola;* and stem borers, mainly *Busseola fusca.* Over 20 species of shoot fly have been recorded in Upper Volta. Infestations are usually low to insignificant except on very late sown crops. Midge attack varies between seasons; it is usually low in the dry Sahelian zone but severe south of latitude 13°N. It is generally insignificant in Nigeria and Mali while "hot spots" have been identified in central and southern Upper Volta. Stem borer infestation is caused primarily by *B. fusca;* however, *Eldana saccharina and Sesamia calamistis* are also found. Severe infestations occur in Nigeria as far north at 12°6' latitude, being most severe at Samaru and Funtua. In Upper Volta, *B. fusca* infestations occur below latitude 11°30'N where annual rainfall exceeds 900 mm. The late crop is most severely infested.

Damage by head bugs and head worms is increasing particularly on introduced sorghums with compact panicles—they are not a problem on local cultivars with loose panicles.

A Comparison of Three Methods for Grain Mold Assessment in Sorghum

V. M. Canez, Jr. and S. B. King

Abstract

Eleven grain sorghums believed to represent a range in susceptibility to grain mold were field grown in Mississippi with and without aerial misting during seed development. At physiological maturity and harvest maturity, threshed grain was assessed for grain mold by (1) visually rating grain for external discoloration, (2) plating surface-sterilized grain to determine fungal infection, and (3) analyzing grain for ergosterol content to determine total fungal biomass. *Fusarium moniliforme, F. semitectum. Curvularia* spp and *Alternaria* spp were the predominant fungi isolated. The greatest number of fungal colonies and highest ergosterol content were associated with misted seed at harvest maturity. Greater differences in fungal invasion among varieties were found with ergosterol analysis than with the plating technique. Visual assessment of grain mold was more closely correlated with ergosterol levels than with total fungal colonies or percent infection.

Sorghum Improvement in Association with Maize

Rene Clara, Napoleon V. Casamalthuapa, Rogelio H. Cordova, Erlberto C. Amaya, and Vartan Guiragossian

Abstract

Sorghum is the second most important cereal (following maize) in Central America. It is most commonly intercropped in a one to one ratio with maize; for example, about 94% of the sorghum sown in Guatemala is intercropped with maize or beans. Sorghum flour is made into *tortillas* directly but generally blended into flour from maize. The degree of blend is influenced by the availability of maize and the market price—if the price of maize is high, it is sold and the percentage of sorghum locally consumed increases.

The sorghum improvement program in El Salvador has most extensively used introductions from Texas A&M University, ICRISAT Center, ICRISAT-CIMMYT, and Puerto Rico directly and in combination with locals to derive earlier, shorter varieties with better grain quality. Selection and evaluation is undertaken in the intercrop. Sorghum is sown in maize and they are in competition for about 68 days when the maize stalk is broken below the ear—at this time the maize is 90 days old. It has been found that the sorghum-maize intercrop (distance between maize-sorghum rows is 45 cm) is more profitable than either as a monocrop. Improved shorter varieties yield 50% more in sole crop and 35% more in the intercrop than local varieties. Best yields are obtained when the maize matures in about 90 days. The lines from El Salvador, ES-412 and SM-1, have been evaluated in Mexico and found to have good quality for making *tortillas.*

Soil Factors and Sorghum Population Optima in Botswana

M. J. Jones, D. Raes, J. Sinciair, and I. Makin

Abstract

In sorghum row-spacing/population trials in Botswana, soil factors strongly influenced crop response to the rainfall pattern. Higher populations had higher rates of water use than low populations on a loamy sand but not on a sandy loam, in which rooting appeared to be restricted by a naturally high bulk density. On this compact soil high populations showed severe drought stress with consequent loss of yield potential, and yields peaked at about 63 000 plants/ha; but on the loamy sand yields increased with population up to at least 140 000 plants/ha. It is postulated that crop performance in a semi-arid environment depends heavily on the ability of the soil to act as a buffer against drought, and this is a function not only of soil depth and water-holding capacity but also ease of rainfall infiltration and root proliferation. Such factors are highly relevant in extension advice to farmers and in land capability evaluation.

Population Improvement in Sorghum in Nigeria

A. Tunde Obilana

Abstract

The population improvement program in Nigeria utilizes four genetically broad-based random-mating populations as base materials, and two main recurrent selection methods: S1 progeny testing and stratified mass selection.

Progress made so far is indicated and discussed comparatively in terms of increased grain yield and *Striga* resistance, for and among the four populations: B composite, Y composite, YZ composite and MSAR composite, using the two recurrent selection procedures. The implication of using the ms7 type of sterility system and its proportion in the original and advanced generation cycles is indicated.

A proposal for the possible use of a combined recurrent selection method: S1 testing plus mass selection (female choice); for an environment with single growing season and additional irrigation, is discussed towards maximizing the genetic gain from selection for yield and multiple disease resistance.

Breeding for Multiple Insect and Disease Resistance in Sorghum

B. S. Rana, V. Java Mohan Rao, V. U. Singh, S. Indira, and N. G. P. Rao

Abstract

Sorghum being predominantly a low input crop of the semi-arid tropics, the simultaneous incorporation of resistance to major pests and diseases in improved cultivars is essential to confer greater levels of stability to production. While individual sources of resistance have no doubt been documented, efforts have also been made recently to identify and develop sources exhibiting resistance to groups of pests and diseases. These will be documented. The mechanism governing resistance to most sorghum pests is nonpreference. Disease resistance as in downy mildew and charcoal rot is a quantitative threshold character. The nature of inheritance is generally additive for threshold characters and for insect resistance. Stability of resistance is also under genetic control. It is possible to develop a genetic basis for multiple resistance and pyramid genes for resistance. The plant breeding implications of breeding for multiple resistance to sorghum pests and diseases will be discussed.

Pleiotropic Effects of g1 Glossy Gene in Sorghum on Leaf Structure, Leaf Digestion, and Disease Resistance

Isao Tarumoto

Abstract

Some of the pleiotropic effects of the g1 glossy gene in sorghum were examined. The outer-side cell walls of cuticles of glossy leaves in SC-112 and Rancher were observed to be thicker and harder than those of nonglossy leaves in Zairai-Token. The nonglossy isogenic plants were always somewhat higher in leaf digestibility than the glossy isogenic plants. This suggests that the thicker and harder cell walls of cuticles in the glossy leaves would be more resistant to the attack of cellulose enzymes than the highly dense epicuticular waxes on the nonglossy leaf surfaces. The relationship between glossiness and resistance to sorghum leaf blight suggests that the resistant gene to leaf blight would be independently inherited of the g1 glossy gene.

Mutational Studies in Sorghum

C. S. Reddy and J. D. Smith

Abstract

In sorghum, induced mutagenesis as a tool for genetic improvement has made only a beginning. Seeds of grain sorghum (Tx-414) were treated with various doses of gamma rays, hydrazine (HZ) and ethyl methanesulphonate (EMS) singly and in combinations, with and without cysteine used as a pre and posttreatment modifier. Hydrazine was found to be a more potent mutagen compared with EMS and gamma rays based on induction of chlorophyll and morphological mutations in the M_2 generation. Cysteine by itself had no toxic effect in M, nor induced any mutations in the M_2, but when used as pre- and posttreatments of gamma irradiated and hydrazine treated material, it afforded protection against seedling injury caused by gamma rays and HZ, and also increased the recovery of chlorophyll and morphological mutations compared with single treatments. Treatments of gamma rays, EMS and HZ in all possible combinations produced less than additive effects for the induction of mutations.

The Role of Sorghum in Rice-based Cropping Systems

D. P. Garrity, V. R. Carangal, and L. D. Haws

Abstract

The development of rice-dryland crop patterns is a response to the need to intensify land use in the densely populated Asian rice-growing areas. It was made possible by the adoption of earlier maturing rices and time-efficient management practices. Sorghum has demonstrated good performance and exceptional yield stability in sequence with rice. This appears to have been due. in particular, to three characteristics: (1) adaptability to heavy paddy soils; (2) superior waterlogging resistance; and (3) drought resistance.

Rice-sorghum is a relatively new cropping pattern. Its present area is small, but the potential area may include millions of hectares. Greater efforts are needed to improve sorghum technology for the unique requirements of the postrice environment, the most critical areas of attention being crop establishment practices and varietal adaptation. Overshadowing these needs at present, however, are the difficulties of developing market channels to sustain production of this relatively new crop in many countries of the region.

Stability of Sorghum-based Intercropping System under Rainfed Conditions

S. P. Singh and D. Jha

Abstract

Most of the earlier studies on the relative stability of intercrop vs sole crop systems under rainfed conditions are based on cross sectional data. It has been suggested that this approach is not conceptually appropriate and one should really look for variability over time. An attempt has been made in this paper to analyze stability of sorghum-based intercropping systems using a more logical model. The data have been taken from experiments conducted by the All India Coordinated Sorghum Improvement Project over the past decade.

A Breeding Procedure for Combining High Protein and High Lysine with Plump Corneous Seeds of Sorghum

V. Jaya Mohan Rao and N. G. P. Rao

Abstract

The transference of the high lysine trait to a plump, corneous endosperm at normal protein levels is yet to be accomplished and distinct guidelines to breeders are not presently available. Based on a comprehensive study involving derived plump and shrivelled lines from the high lysine Ethiopian parentage and P-721, it has been possible to identify crosses which did not exhibit the general negative relationship between protein and lysine. The studies yielded data on criteria for choice of parents, the direction of the cross, character associations, nature of gene action and mating systems.

Note on Sorghum insect Pests in Upper Volta

S. M. Bonzi

Abstract

Sorghum is the main food crop in Upper Volta. The most common insect pests are sorghum midge, stem borer *(Busseola fusca)* and shoot fly. The drought that occurred in the seventies in the Sahel Region of West Africa favored some less polyphagous pests, *Poophilus costalis* and *aphids* being among them.

Consumer Preferences and the Adoption of New Cultivars in Sahelian West Africa

W. M. M. Morris

Abstract

About 85% of the sorghum and millets produced in West Africa is consumed by the producer—it does not reach a market. Over the past 15years the rate of increase in production of sorghum and millets has been 1.8%, year with a population increase of 2.8%/year. Coastal countries, Senegal, Mauritania, and Gambia, have been increasingly importing wheat and rice at the rate of about 10%, year. While there are organized grain markets there is a failure to guarantee price because of a lack of ability by the government to buy, store, and market a surplus crop. Market prices fall and the farmer loses incentive to produce.

The farmer has an array of varieties and he sows them according to such factors as soil type and fertility, rainfall, risk aversion and consumer preference. There are changes in food habits; the younger generation may prefer to eat pasta noodles or spaghetti rather than traditonal td resulting in differences for grain type within a family. Preferences for good milling quality, color, clean, insect-free sound seed exist both in the market as well as the home. A better understanding of indigenous knowledge on varietal preference is important.

The Contribution of IRAT to the Development of Sorghum Varieties and Hybrids in West Africa

J. Chantereau

Abstract

Initially, in the early 1960s, ecotypes such as Muskwari in Cameroon, Belko and Gnefing in Upper Volta, Tiemarifing in Mali, Jan Jare and Mourmour in Niger, Congossane SH60 in Senegal were developed by mass and pedigree selection within locals. A second stage involved the development of earlier, shorter varieties with more compact heads and tan straw—exotic lines were used. A series of hybrids (IRAT S12 and IRAT 179) and varieties [(IRAT S6. S7, S8 in Upper Volta, IRAT S10 in Niger, IRAT S11 (CE90), S13 (CE67). S15 (CE99) and (CE111)] in Senegal were developed. Crop management was found important if increased yields were to be realized from these new varieties and hybrids. Traits such as resistance to grain mold and food quality were also found to be important. Recent selection for varieties and hybrids involves these traits plus seedling vigor and related factors contributing to stand establishment. Promising lines are CE 145-66, CE 151-186, CE 151-262, and CE 157-95.

New seed parents for hybrids have been developed and CE 102A and B and CE 111 A and B are useful in Senegal. In the north of Senegal, with irrigation, CSH-9 from India, CK 612A from USA. R 75-14 from ICRISAT and the IRAT hybrid 181 are performing well. The importance of linking new varieties and hybrids with improved management practices is emphasized.

Appendix 2
Poster Sessions

Poster Session

The following papers appeared in poster sessions. Copies can be obtained from the authors.

Seedling Emergence in Sorghum under Varying Soil Temperature and Moisture

P. Soman and J. M. Peacock

Abstract

Emergence response of a few sorghum genotypes to different soil temperatures were tested in a system where wet soil could be heated from above. Temperatures of 35°C, 40°C, 45°C and 50°C were maintained at a depth of 2 cm. Genotypic variability was detected. Hybrids CSH-1, CSH-5, and CSH-6 showed poor emergence at high temperatures compared with varieties such as SPV 354, SPV 386 and SPV 387. The cultivars were also tested for emergence under limited soil moisture. Three levels of soil moisture were maintained in pots: 3.8-0.3%, 7.5-2.1%, and 8.1-3.2%. Again, hybrids gave very low emergence at lower moisture supply when compared with varieties. Genotypic variability was detected.

Strategies for Drought Tolerance

H. G. Jones

Abstract

The results of calculations using a simple model to investigate the relative advantages of *conservative* or *optimistic* strategies of water use for crop productivity in different climates are described. In particular the implications of the fact that the occurrence and amount of rainfall in many semi-arid environments are more or less variable from year to year will be investigated.

Sorghum Genotype Differences to Organic and Inorganic Sources of Phosphorus

A. M. Furlanl, R. B. Clark, J. W. Maranville. and W. M. ROM

Abstract

Selected sorghum [*Sorghum bicolor* [L] Moench) genotypes, chosen because of their response to low P in earlier studies, were grown in nutrient solutions and in a low P soil with various organic and inorganic sources of P to determine their differences for dry matter yields, P concentrations and contents, dry matter produced per unit P, and P distribution among plant parts. Plants grown with organic sources of P. whether in nutrient solutions or in soils produced more dry matter and had higher P concentrations and contents than genotypes grown with inorganic sources of P. Plants grown with calcium phosphate compounds produced as much or more dry matter as plants grown with KH_2PO_4 in nutrient solutions, but less when grown in soils. Plants grown with ferric, ferrous, and aluminum phosphates produced the least dry matter in both nutrient solutions and in soils. Widest differences among genotypes for dry matter yields were noted for plants grown with ethylammonium phosphate, calcium tribasic phosphate, glycerylphosphate,and KH_2PO_4. Plants grown with KH_2PO_4 and calcium tribasic phosphate had nearly 6-fold higher dry matter produced per unit P than plants grown with ethylammonium phosphate. Genotypes showed few differences in P distribution between roots and tops, but differed extensively in P distribution among lower, middle, and upper leaves. Of the genotypes studied, BB-9040 was the most tolerant to low P and SC-33-9-8-E-4 was the least tolerant.

Acetylene Reduction Activity of Several Sorghum and N_2-Fixing Bacterial Associations

S. C. Schank, Rax L. Smith, and J. R. Milam

Abstract

Fifty-one *Sorghum vulgare* (L.) Moench lines were tested in replicated field plots for acetylene reduction (AR). Range of AR activity was from 0 to 1934 nanomoles per gram of dry root per hour. In order to further study these highly variable field responses, an in vitro screening technique has been developed to evaluate plant responses, root bacteria associations, and acetylene reduction of specific grass bacteria combinations. Axenic systems using diverse sorghum germplasm were established by inoculating sorghum plants with *Azospirillum* or other N_2-fixing bacteria. The seedlings were grown in test tubes for 10 days on a Fahraeus, nitrogen and carbon free medium. In addition, bacterial populations of *Azospirillum* were studied at the end of the growth period using fluorescent antibody labeling. Roots were scored for root-bacteria associations. Photos of the root-bacteria associations will be displayed.

Embryo and Endosperm Formation in Cross-Sterile Facultatively Aposporous Apomicts

M. Bharati, U. R. Murty, and N. G. P. Rao

Abstract

Twenty-one cross-sterile cultures were isolated in advanced generation progenies of crosses involving the facultative apomict R-473, and a sexual line, White Seed. Four of these cross-sterile lines were examined at various time intervals up to 4 days. A considerable number of embryo sacs remained unfertilized at various time intervals. Lack of fertilization was concluded from the presence of intact synergids, unfused polar nuclei of the central cell and the undivided egg. The frequency of such embryo sacs approached 20%. The unfertilized egg was seen to give rise to an embryo starting from the 2nd day after pollination. Endosperm also formed simultaneously, but the endosperm nuclei presented an appearance different from that of sexually formed endosperm. The antipodal nuclei were seen to have contributed to such endosperm at least in some cases. Pollen tubes were found to continue growth in nuceli that were more than 3 days old. Thes6 observations were taken to indicate that pollen tubes cannot penetrate aposporous embryo sacs and that embryo and endosperm in such embryo sacs occurred autonomously a few days after anthesis.

The Starch for Apospory in *Sorghum* L

V. Seshavatharam and U. R. Murty

Abstract

The possibility of producing perpetual hybrids in sorghum has prompted an investigation of the embryology of *Sorghum halepense. Sorghum halepense* was on record as having some apomictic tendencies as revealed through its breeding behavior. The mechanism underlying such a behavior could be due to the occurrence of apomixis in the aposporous embryo sacs, as the embryological study of this species reveals the existence of somatic apospory in some ovules that are potentially capable of developing into an aposporous embryo sac. The aposporous initials could be discerned in slightly older ovules, only after the differentiation of the megaspore mother cell or its further development.

Chromosomal Structural Hybridity and Breeding Systems in *Sorghum bIcolor* (L.) Moench

P. B. Kirti, U. R. Murty, and N. G. P. Rao

Abstract

The study was undertaken to find out whether sexuality, cross-sterility and apomixis have any chromosomal basis. A facultatively apomictic line (R-473), a cross-sterile line (101), four normal lines (White Seed, Kafir-B. IS-84 and Aispuri) and four F_1 hybrids were examined at the mid-prophase stage of meiosis. Unpaired chromosomal regions were noticed at the pachytene stage in the apomictic and cross-sterile lines but not in the normal sexual lines. F_1 hybrids between normal sexual lines (Kafir-B x Aispuri) did not exhibit any abnormalities in chromosome pairing but those between sexual and apomictic lines were structurally heterozygous. Chromosomal structural differences can, therefore, result occasionally in abnormal breeding systems including apomixis. This study indicates that crosses between divergent materials may help achieve obligate apomixis.

Developmental Studies in Cytoplasmic Genetic Male-sterile Sorghum Lines

L. L. Narayana, R. N. Reddy, N. G. P. Rao. and K. D. Pillal

Abstract

The develoyment of anther, male gametophyte, ovule, and female gametophyte in the male-sterile sorghum lines, G-1A, CK-60-A, VZM-2-A and M-35-1 has been studied. Abnormalities such as intratapetal syncytia, thickening of tapetal cell walls, abnormal radical elongation of tapetal cells, early disorganization of tapetum and cytomixis are responsible for male sterility in these lines. The embryo sac develops according to the polygonum type and is thus sexual. Because of pollen sterility, fertilization fails to take place under selfing. In the absence of fertilization, sexual embryo sacs degenerate and consequently there is no seed set. However, in G1A and CK-60-A a tendency for the formation of aposporous embryo sacs and degeneration of the megaspore mother cell on the products of meiosis has been noticed. By continued selfing it may be possible to induce apomixis in these lines.

Biochemical Basis of Diverse Cytoplasmic Genetic Male Steriles in Sorghum

D. P. Tripathi, S. L. Mahta, and N. G. P. Rao

Abstract

Study of soluble protein and isoenzyme in seeds and amino acids in anthers of different steriles, maintainor and restorer lines showed characteristic differences. Based on esterase pattern, male steriles with diverse cytoplasm could be organized into three groups: (a) CK-60 A and B, Nagpur A and B, (b) M-35-1 A and B, and (c) G-1A and B, VZM-2A and B. Comparison of amino acids from anthers of A vs B lines showed lower contents of histidine, threonine, glutamic acid, glycine, leucine and phenyl alanine and higher contents of alanine, serine, proline and tyrosine in A lines than B lines. VZM-2 pollen showed resemblance to G-1 pollen but differed from both CK-60 and M-35-1 pollen in shape, size and exine sculpture. The pollen from male-sterile lines were more or less devoid of protein and starch particles.

Resistance Breeding to Sugarcane Mosaic Virus in Australia

R. G. Henzell, D. M. Parsley, R. S.-Greber, and D. S. Taakle

Abstract

A breeding program to incorporate the single gene "K" from Krish for resistance to sugarcane mosaic virus (SCMV) and the multigenic field resistance from Q-7539 into the grain sorghum lines KS-4, TAM-422, R-7078 and KS-19 has been conducted in Queensland.

Nineteen lines with the "K" gene have been released. Two of these, QL-3 and QL-22 are also highly resistant to sorghum downy mildew. QL-19, with Q-7539's resistance has also been released.

An international survey of SCMV strains on 10 sorghum differentials has indicated the wide spectrum of resistance to SCMV strains of the single gene Krish resistance.

A Rapid Technique for Evaluating Sorghum Varieties for Seed Mold Resistance

Natale Zummo

Abstract

Because the nature of resistance of sorghum lines to grain molds is variable and not clearly defined, a method of selecting lines that could produce good quality grain under conditions of high humidity without losing quality would be desirable. Threshed grains of test lines are compared with a known set of molded grains using a large 10x illuminated lens and rated on a scale of 1-10 with 1 being completely free of molds and 10 being completely covered. A set of white and red differentials is needed when comparing red and white seeded sorghum lines. In West Africa, those lines planted earlier and exposed to the rains had a higher seed mold rating than the same lines planted 2-3 weeks later. However, those lines that were superior in grain mold resistance remained relatively superior whether planted early or late.

A Grain Yield Development in a Hybrid Sorghum (Texas 610) and its Parents

U. Jayasuriya and G. L. Wilson

Abstract

Grain yield corresponds closely to the storage of carbon assimilated during the grain filling period. In the female parent, the amount of material available for such storage is high, but the small number of grains limits yield. In the male parent, the large number of grains provides adequate storage capacity, but the supply of material for storage limits yield. This is because canopy structure is poor and hence the efficiency of photosynthetic conversion of solar radiation is low. The hybrid combines the desirable features of the two parents; good canopy structure and high grain number.

Grain Yield Compensation in Rainfed Sorghum

R. I. Hamilton, V. Balasubramanlan, M. Narayana Reddy, and C. Hanumantha Rao

Abstract

In rainfed sorghum hybrid CSH-6, various proportions of spikelets from the apex, base or random regions of the panicles were removed at the time of anthesis, and compensation in yield components was investigated. The distribution of grain number and grain weight from apex to base in untreated panicles was parabolic while grain size showed a progressive linear decrease. Full grain yield compensation occurred due to an increase in grain number and size when the panicles lost up to 20% of the spikelet portions at the base or at random. The data on grain number compensation and the decreasing grain size from apex to base of the panicles indicate hormonal involvement also in the determination of potential grain number and size.

Problems and Perspectives of Grain Sorghum Cultivation in Italy

G. Mariani

Abstract

Peninsular Italy, as other Mediterranean environments, makes sorghum cultivation possible in a range of situations, and as an alternative to maize, at least in marginal areas, under rainfed conditions or with irrigation, as the main crop or second crop after wheat.

Cultivation is based on hybrids, double dwarf types from the USA. The yield performances are economically interesting. The main difficulty is obtaining uniform and suitable stands if sowing is not followed by irrigation. While diseases do not represent a serious constraint, sorghum shoot fly and sorghum midge adversely affect cultivation in some areas. Birds may cause severe crop losses in isolated small fields.

The main objective of sorghum improvement is to produce hybrids (adapted to drought conditions and suitable for early or deep sowing), whose seed should be produced in our conditions; they also need some resistance to birds, but with a reasonable tannin content in the grain.

Inter- and Intraspecific Competition and the Design of Productive Cropping Systems

B. S. Rana, P. P. Tarhalkar. and N. G. P. Rao

Abstract

Competition between species results in their characterization as complementary, aggressive or relatively neutral species. Alteration of plant type within a species renders them more-or-less competitive. Data on inter- and intraspecies competition with sorghum as a component crap will be presented. Keeping in view the recent changes that have occurred in sorghum cultivars, the complementarity or compatibility of sorghum-based cropping systems both in space and time will be examined. The design and development of stable, productive and transgressive cropping systems will be analyzed.

Factors Affecting Sorghum Consumption in Honduras

Mary Futrell, Eunice McCulloch, Robert Jones, and Louis Bluhm

Abstract

This interdisciplinary research dealt with the agronomic, economic, social and nutritional factors which influenced the production, storage, and consumption of sorghum in Honduras. An interview schedule covering the above areas was developed and used by Mississippi INTSORMIL researchers in two surveys in the summer of 1981 in mountainous and lowland areas of southern Honduras. Data on household size, sex roles, decision-making patterns, attitudes, values, consumer preferences of grain and methods of food preparation were recorded. Food intake studies, as well as anthropometric measurements, were used to assess the nutritional status of each child. This was a base-line study to develop criterion for future nutritional improvement through the use of improved strains of sorghum grown in Honduras for human consumption.

Nitrogen Fixation Associated with Sorghum

S. P. Wani, P. J. Dart, S. C. Chandrapalalah, and M. N. Upadhyaya

Abstract

Using a soil-core assay method in the acetylene reduction technique, 334 lines have been screened; 55% of the lines tested stimulated N_2-ase activity in the rhizosphere and 14% stimulated high activity (100 μg N/core/day). The activity is affected by field variability, time of sampling during the day, and the time interval between taking the core and injecting C_2H_2. Activity varied not only with the growth stage of the crop when assayed, but also with the temperature at which the cores were incubated during assay and the amount of nitrogen fertilizer added. Activity is well correlated with the soil moisture. A test tube culture technique has been developed to test the effect of host genotype and bacterial culture on nitrogenase activity. A method for assaying intact plants for nitrogenase activity has been developed. By using this method the same plant can be assayed several times during its growth cycle and seed can also be obtained. In a pot experiment with the sorghum hybrid CSH-1 grown in unsterilized Alfisol soil, inoculation with nitrogen fixing bacteria produced a significant increase in grain and total dry matter production.

Nitrogen-fixing Bacteria Associated with Sorghum

D. B. Godse. P. J. Dart, and K. P. Habbar

Abstract

The total number of N_2 fixers from rhizosphere soil, rhizoplane and root macerate of sorghum plants was estimated by plate counts using N-free sucrose and malate media. Using these inocula, nitrogenase activity was measured by the most probable number (MPN) method on sucrose and malate semisolid media. Nitrogenase activity was measured by the acetylene reduction technique. Value of the spermosphere model was demonstrated with plants grown in tubes on Fahraeus agar medium for selection of the most abundant and host compatible bacteria from the rhizosphere soil, rhizoplane soil and root macerate. Based on colony morphology, various isolates were picked up from plates and purified. Purified isolates were tested for nitrogenase activity on malate and sucrose semisolid media with 20% acetylene incubated for 3 hr at 33°C. Applicability of analytical profile index (API) tests was demonstrated for quick identification of nitrogen fixers belonging to Enterobacteriacae.

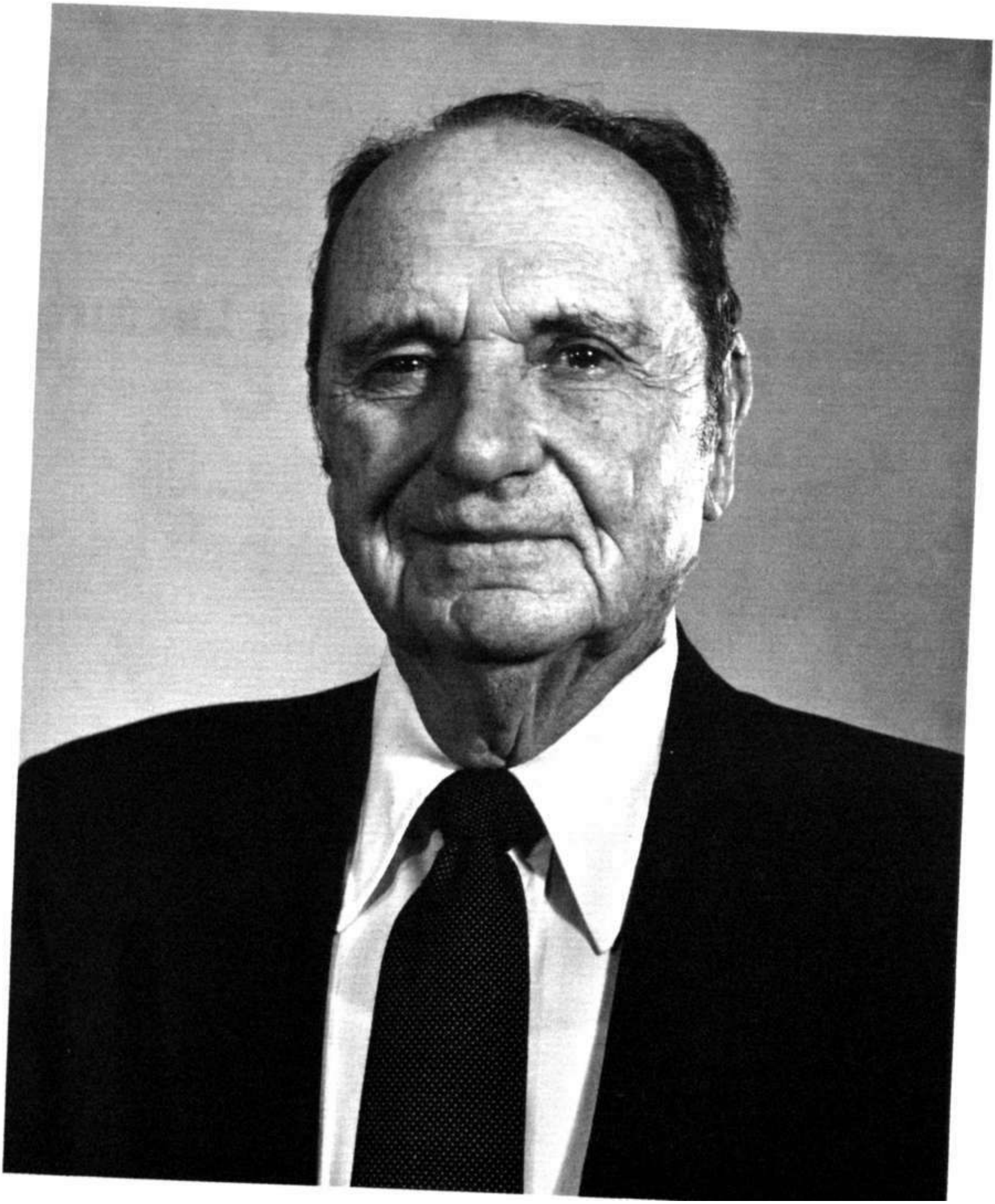
A New Sorghum Program in the SAT in Australia

L J. Wade

Abstract

A research program is being initiated to investigate sorghum productivity in the Capricornia region of Queensland, Australia. This region of expanding dryland sorghum production is characterized by heavy cracking clay soils in the SAT where antecedent soil moisture is important and rainfall irregular. There is enormous potential for the crop in this region but performance of existing cultivars has been disappointing so far. Initial experimentation will be directed to defining the exact nature of limitations to productivity in this environment. Other work will involve phenology, crop establishment and growth analysis, which are all likely to be important in this region.

Appendix 3
Presentation of Award and Lecture



Presentation of Award

J. Roy Quinby was presented with a marble mosaic plaque with the following inscription:

In recognition of 57 years contribution to our knowledge of sorghum by the delegates of the Sorghum in the Eighties Symposium, Hyderabad, India.

November 2-7. 1981"

J. Roy Quinby was employed to work on sorghum at the Chillicothe Station at Texas A&M University in 1924, 57 years ago. One of his earliest publications appeared in 1931. He became superintendent of the station in 1925 and at that time his lifelong associate, J. C. Stephens was also employed there.

Mr. Quinby has pioneered our knowledge of the inheritance of maturity in sorghum with the first publication appearing in 1945. He also undertook the study of the genetic control of plant height and published in 1954. The understanding of the inheritance of these two traits has been fundamental to all sorghum scientists working to adapt sorghum to new areas or new situations leading to improved production.

Mr. Quinby has had a long interest in the commercial use of hybrids including the use of male sterility to facilitate seed production.

There are major papers concerning hybrid vigor that were published by Karper and Quinby in 1937, and by Stephens and Quinby in 1952. Results showing substantial increases in yield due to hybrid vigor were presented in these papers. I would like to read from Mr. Quinby's own writing in a TAES publication "A Triumph of Research....Sorghum in Texas." "Dr. R. D. Lewis came to Texas in 1946 to be Director of the Texas Agricultural Experiment Station. While he was visiting at the Chillicothe Station I showed Dr. Lewis a manuscript that contained a picture with the caption The use of hybrid vigor in sorghum awaits the solution of problems in the economical production of hybrid seed.

"Before Dr. Lewis left the Chillicothe Station that day he told Stephens and me that he would approve a proposal for research on methods of producing hybrid sorghum seed if we would prepare such a proposal." Roy Quinby and his associates undertook to implement Hatch Project 610 dated 4 October 1947. The objective of this project was to produce seed of sorghum hybrids in commercially useful amounts.

In 1948 Stephens felt that he had identified cytoplasmic male-sterility. Again quoting Mr. Quinby, "Early one morning in 1952 Stephens and I decided that cytoplasmic male-sterility looked too good to abandon" and work on other mechanisms of male-sterility were terminated. By 1955, seven hybrids were considered to be useful for farmer production. Mr. Quinby and J.C. Stephens shared the Hoblitzelle Award for The Advancement of Texas Rural Life.

Events moved rapidly; by 1957 there was sufficient hybrid seed to sow 15% of the sorghum acreage in the USA and by 1960 some 95% was sown. Hybrids combined with irrigation and increased use of fertilizer increased sorghum production in the USA threefold with little increase in acreage.

Mr. Quinby joined the Pioneer Seed Company in 1961 after retiring from the Texas A&M University. Quinby made the first cross to start a conversion program in January 1962. J. C. Stephens prepared a proposal to undertake a tropical conversion program using facilities of the U.S. Department of Agriculture in Puerto Rico in the tropics and those of the Texas Agricultural Experiment Station, at Chillicothe, in the temperate zone. The proposal was approved by the Texas Station and U.S. Department of Agriculture in June 1963 and work began at Mayaguez, Puerto Rico, in the fall of that year. All sorghum scientists are aware of this conversion program and most of them are using converted lines in their breeding programs. This program has been invaluable as a source of resistance traits and has contributed to yield improvement in many places in the world.

Today, Roy Quinby is actively involved in the genetics of hormonal control of sex in sorghum. This knowledge of genes and cytoplasms influencing the fertility-sterility relationship in sorghum can lead to valuable practical information, particularly in relation to apomixis as a means to the vegetative production of hybrid seed, and the question of genetic vulnerability in our hybrid seed parents.

J. Roy Quinby, throughout his working life, has made contributions to our knowledge of grain sorghum that have and will continue to have a profound effect on the improvement of the crop in every location in the world where sorghum is grown.

L. R. House

4 November 1981

Lecture After Presentation of Award

Sorghum Genetics and Breeding

J. R. Quinby*

I appreciate this opportunity to speak to you about sorghum genetics and breeding as they have developed in my lifetime and to try to recognize what still needs to be done. It is delightful to see many of you again and to meet those of you who are just starting a career working with sorghum.

Early in my career I became superintendent of a local experiment station in Texas and I had many duties that did not involve sorghum. But, as time progressed, my vocation became sorghum genetics and breeding. J. C. Stephens joined me at Chillicothe, Texas in 1925 as a full-time sorghum breeder and he worked on sorghum during his entire career. His chief accomplishment was the development of hybrid sorghum using cytoplasmic male sterility. Sorghum hybrids emerged after about 25 years of work. Since the advent of sorghum hybrids, grain sorghum production in the United States has increased threefold.

As Stephens and I began to work on sorghum genetics, we discovered that, as we were just about ready to publish on the inheritance of some character, a paper from India would appear on the same subject. I presume you realize that the earliest work on sorghum genetics was done in India and much of it by G. N. Rangaswami Ayyangar and his students at Coimbatore.

A significant advancement in sorghum research was made when the Rockefeller Foundation began to support the work of the Indian Agricultural Research Institute. Dr. K. O. Rachie became involved in the work with sorghum and the Rockefeller Foundation is responsible for assembling the sorghum varieties being grown throughout the world into a single world collection.

It is apparent that the sorghum cultivars in that collection are the product of thousands of years of natural and human selection. I have become familiar with only that part of the collection that was first converted to temperate adaptation (Johnson et al. 1971). But it is evident that characteristics that are now valuable to us were selected by men and women who intended to eat the grain themselves. Cultivars in the collection have been evaluated at several locations and many have agronomic characteristics that are valuable because they include resistance to insects, diseases, and weathering that plague sorghum throughtout the world. Disease resistant converted lines have been identified recently by Frederiksen and Rosenow. (1979) and insect resistant lines by Johnson and Teetes (1979). As time progresses, plant breeders will need to use all the desirable characteristics of varieties in the world collection.

After the world collection of sorghum was assembled here in India, it became apparent that the desirable characteristics in varieties in the collection should be made available to plant breeders in the temperate zones. It was already known that the difference between tropical and temperate adaptation depended upon the dominant or recessive condition of a single gene (Quinby and Karper 1945; Quinby 1973). Also, dwarfness is inherited simply (Quinby and Karper 1954) and a tropical conversion program was undertaken by the Texas Agricultural Experiment Station and the United States Department of Agriculture. This conversion program that was described by Stephens et al. (1967) and recently by Miller (1979), consists of the incorporation of

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International Crops Research Institute for the Semi-Arid Tropics. 1982. Sorghum in the Eighties: Proceedings of the International Symposium on Sorghum, 2-7 Nov 81, Patancheru. A.P., India. Patancheru, A.P. India: ICRISAT.

one recessive maturity gene and two or three recessive height genes into the chosen tropical varieties. The tropical conversion program has proceeded according to plan without a single necessary change. Fortunately, the project proposal included the provision of returning each converted cultivar to its own cytoplasm at the last backcross.

I am sure that my interests are too narrow for me to have good judgment about what you and those who follow you may be doing in the near and distant future. However, I now recognize some of the misconceptions that I labored under for many years and think I recognize some research work that should be done now.

As Doggett (1970) has suggested, sorghum probably evolved in tropical Africa and spread to temperate zones and to other continents within the last 2000 years. Sorghum has been in the western hemisphere for only about 200 years and only a very few varieties, including the questionable relative *S. halepense,* arrived even then. But now that the tropical conversion program has been under way for about 20 years, plant breeders throughout the world have many of the desirable varieties from tropical Africa and India available to them. Also, if you as plant breeders in the tropics are interested in shorter heights, you should realize that tropical "bulks" are available from the conversion program that should be of interest to you.

Sorghum has been a good crop to work with as inheritance in the species seems to conform to the principles recognized by Gregor Mendel about a century ago.

When I visited a graduate course in plant breeding just before I graduated from Texas A & M College in 1924. I received the impression that genes that control growth were innumerable and that any plant included in its hereditary complement numerous minor metabolic deficiencies. These ideas grew out of the efforts to explain the genetics of hybrid vigor. East and Jones (1919) in their textbook said that "it is only necessary to assume that in general the favorable characters are in some degree dominant over the unfavorable, and the normal over the abnormal in order to have a reasonable explanation of the increased development of hybrids..." Of course, plant hormones were not known at the time because Went (1928) had not yet reported the recognition of auxin as a growth regulator.

In 1937, I was coauthor of a paper on hybrid vigor in sorghum (Karper and Quinby 1937) that contained good data and some beautiful pictures. But some of our conclusions became an embarrassment to me later because we had not recognized that it was the complementary action of a few height and maturity genes that had resulted in much of the added growth that we had observed and attributed to hybrid vigor.

It finally became common knowledge that self-pollinated species should not carry numerous metabolic deficiencies and as late as 25 years ago there were geneticists (Sinnott et al. 1958) who thought that hybrid vigor should not occur in a self-pollinated species. But that notion had to be abandoned when hybrid vigor was shown to be present in self-pollinated species such as sorghum.

Grain sorghum yields did not increase in the United States until hybrids appeared but the genetic and physiological basis of hybrid vigor is still not understood. A few years ago I reviewed the literature on the genetics and physiology of hybrid vigor (Quinby 1974) and presented the idea that parents and hybrids differed in hormone levels. But hormone levels in parents and hybrids have not yet been examined. But the idea that numerous genes control plant growth is still with us and is part of the basis of the theories of population improvement.

During the time I was studying the inheritance of maturity and height (Quinby and Karper 1945 and 1954), I developed maturity genotypes in identical genetic backgrounds that differed at three maturity gene loci and three height gene loci. I finally concluded that the genes controlling the time of floral initiation and intemode elongation were probably controlling hormone levels. I then presented my ideas (Quinby 1974), without proof, hoping that some plant physiologist would use the maturity and height genotypes to study the hormonal control of. plant growth.

Dr. P. W. Morgan at Texas A & M University and several of his students have been determining hormone levels in maturity genotypes of Milo and papers covering that work are beginning to appear. Gibberellin is now known to hasten floral initiation in sorghum (Williams and Morgan, in press) and that auxin levels are higher in tropical than in temperate Milo genotypes (Dunlap and Morgan, in press). It is assumed that inhibitory levels of auxin delay floral initiation of tropical varieties being grown in temperate zones.

In addition. Dr. F. R. Miller and I, using solutions prepared by Dr. Morgan, have been trying to duplicate the action of height and maturity genes of Milo. In the field, we have not done as well as we had hoped, apparently because auxins such as indole acetic acid (IAA) are destroyed before they have time to act within the plant. But we have done better with gibberellin and one paper on the effect of GA3 on height and tillering has appeared (Morgan et al. 1977). Treatments with GA3 to short genotypes increased height by as much as the presence of one dominant height gene.

In looking for new male-sterile-inducing cytoplasms, I (and Dr. K. F. Schertz, as well) used the first 62 tropical conversions that originated in the tropical conversion program. Several F1 populations were male sterile, numerous F2 populations contained male-sterile plants, and 33 cultivars were involved as female parents. It finally became evident that a Kafir could be male-sterilized in three different cytoplasms, and four different cytoplasms have now been recognized in sorghum (Quinby, in press). A fifth cytoplasm, that should exist, is being sought.

Earlier work to identify different cytoplasms has been done in India and this work has been reviewed by Tripathi (1979). It is difficult to work in Texas with the varieties that have tropical adaptation and are late in maturity in the temperate zone. Nevertheless, it is apparent now that the Maldandi source in male-sterile M-85-1 is similar to "A3" that was recognized recently in the United States (Quinby, in press) and came from the Indian variety Nilwa.

Now that a single genotype exists in four cytoplasms, plants of one genotype can be grown that can be analyzed for hormone levels. This genotype in its own cytoplasms has perfect, hermaphroditic flowers but in the other three cytoplasms exhibit slightly different types of male sterility in each. Dr. Morgan intends to look into hormone levels within the three male steriles and the one perfect flowered genotype and the male and female hormones will probably soon be identified.

It is now possible to produce sorghum hybrids of the same genotype in three different cytoplasms and, if the hybrids turn out to be slightly different, some hormone physiologist might like to look into this aspect of the physiology of hybrid vigor.

As work looking for new cytoplasms progressed at Plainview, Texas, it became obvious that apomixis was appearing in some segregating populations. You may remember that both Drs. N. G. P. Rao and U. R. Murty reported on apomixis at the 1970 Symposium. Dr. Murty has continued to be active in studying apomixis in India, and in Texas as well, and reports of his work in cooperation with Drs. E. C. Bashaw and K. F. Schertz have been published (Murty et al. 1979).

The genetics of apomixis is not yet completely understood. R-473, the apomictic strain that Dr. N. G. P. Rao was good enough to send.to Texas, is apparently a facultative apomict. It is my present opinion that the genotype of R473 in some different cytoplasm might well be an obligate apomict. Apomictic hybrids are probably not needed in the United States because it is too easy to produce and sell hybrid seed there. But where only small amounts of seed are needed on small farms, apomictic hybrids might be extremely useful.

Also, hybrid vigor is not being used in such crops as soybeans, and even wheat because of the difficulty of producing hybrid seed. I think that an understanding of the genetics of obligate apomixis in sorghum is likely to promote the recognition and use of apomixis in species where hybrid vigor cannot be used at present.

At the present time, the testing of hybrids to recognize maximum hybrid vigor at numerous locations is a major activity in many breeding programs and literally thousands of hybrids are tested and all but a very few are thrown away. This is an inefficient process but no suitable substitute has been devised by commercial seed companies to identify hybrids with maximum hybrid vigor. Plant breeders in the public sector can make a real contribution if they produce varieties or parents that carry the desirable genes that result in resistance to diseases or insects or in better nutrition.

In countries where agriculture is mechanized and sorghum is a cash crop grown on large acreages, maximum hybrid vigor continues to be a major requirement. Unfortunately, insect problems do not remain static as attested by the emergence of biotype C of the greenbug, *Schizaphis graminum* Rond. in the United States in 1968. This pest of wheat finally developed a taste for sorghum and, after 10 years, biotype E has now emerged that develops well on hybrids tolerant to biotype C. Also, experience has shown that hybrids that are resistant to certain diseases in the United States are susceptible to some other races of the same disease in Mexico, the Philippines. South Africa, or Australia. This problem of a change in races of insects or diseases will apparently continue to be with us and plant breeders will need to continue to be alert and ready to take care of the problems as they arise. And the breeding program will always be complicated by the fact that any disease- or insect-resistant parents that emerge must produce hybrids that have acceptable levels of hybrid vigor.

There are people in the world who look upon modern technology as a menace to society and who think that plant breeders like us are courting disaster for the human race. "Genetic Vulnerability of Major Crops" (Horsfall 1972) is the title of a book that points out the danger inherent in plant breeding procedures that result in a single hybrid or variety being grown extensively on large acreages.

This danger is real but isoveremphasized, in my opinion. If one thinks that plant growth is controlled by innumerable genes, one would think that some diversity, that might be needed later, is lost if only one variety is lost. If, on the other hand, one thinks that a relatively few genes control growth and the rest of the dominant alleles result only in normal plants, one would not be particularly concerned about the loss of some varieties as is inevitable as plant breeding produces improved strains and hybrids.

The numerous genes that are not involved with the regulation of plant growth, such as those that produce normal chlorophyll, must be present in the dominant condition, otherwise the plant will be abnormal. Such dominant genes are not lost in the plant breeding process to improve the species or to use hybrid vigor. All genes appear to be useful to the species, but in breeding for adaptation or yield, plant breeders should be chiefly interested in genes that control the amount or rate of growth or time of differentiation.

The desirable genes that exist in sorghum today, and are in hand, should be incorporated into cultivars or into parents of hybrids that are adapted to the many diverse environments in which sorghum is now being grown or may be grown in the future. For instance, sorghum cultivars from high elevations in Ethiopia might well contribute alleles that might result in hybrids adapted to high elevations in the subtropics or at high latitudes where prevailing temperatures in the summer are low.

Unfortunately, marketing practices in the United States will be a problem to farmers who might wish to produce a white-seeded, non-weathering, highly nutritional sorghum hybrid. Grain of such a hybrid would, at present, result in a discount at the elevator if mixed with the red grains of the hybrids commonly grown. But such difficulties should not deter plant breeders from working to improve sorghum nutrition because some suitable marketing procedure can undoubtedly be developed when needed.

I see more plant breeding objectives today than when I began to work on sorghum more than 50 years ago; not because there are more problems, but because we now recognize more things that should and can be done. In the United States, we do not have all of the problems that some of you have because we do not have some of your insects, diseases, or parasites. But we have some problems that you do not have.

We, as plant breeders, should stay as close to entomologists, plant pathologists, geneticists, and plant physiologists as possible so that we can profit from their knowledge and advice. I hope that you realize how important your work with sorghum is and that you get as much pleasure in your activities as I do in mine.

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Appendix 4
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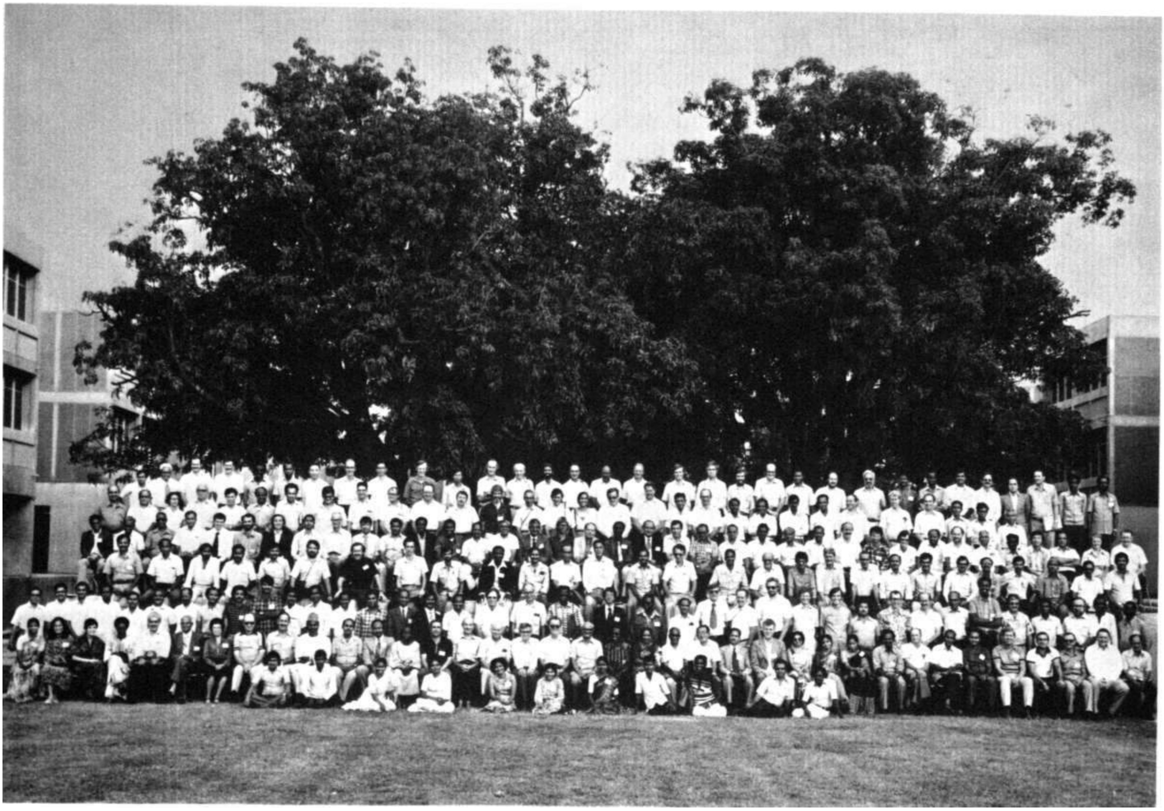

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