Semi-Arid Tropical Rainfed Agriculture: Opportunities and Challenges

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INTRODUCTION

According to the Asian Development Bank (1989) rainfed agriculture is defined as agriculture based on crop production in a farming system which depends entirely on rainfall on particular land-holdings. It excludes irrigation from streams and underground sources, but may include supplementary irrigation from small dams or tanks fed from rainfall and associated runoff on particular landholdings. Rainfed farming systems are usually diverse, integrated with livestock systems, and often include perennial crops (and tree species).

In general, rainfed agricultural technologies tend to be specific to the physical, social, and economic environment in which they were developed, and, in order to have any measurable impact in a different environment, must be modified and adapted to the specific new conditions.

According to Brady (1988) rainfed farming is practised on about 40% of the world's land surface, 60% of this rainfed area is in the developing countries. Adverse soils; high air and soil temperatures; destructive insects and diseases; and low and unpredictable rainfall that often falls in intensive storms are all typical major constraints that limit agricultural productivity on the 600 million ha of land devoted to rainfed agriculture worldwide.

In this paper we will largely concentrate on the semi-arid tropical (SAT) rainfed agricultural regions of the developing world where some 800 million poor people eke out an existence. These people live in over 50 countries of the SAT and their resource endowments are very poor by most standards. The land on which they farm is mostly suitable to grow only one crop per year. Due to climatic variability, there is a perpetual risk of reduction in crop yields because of drought leading to reduced crop yields or even total crop failure. In the past, the farmer had access to a variety of options to stabilize his or her income from rainfed farming. The choices included dependence on animal-based farming systems rather than total dependence on arable farming; fallowing parts of the farm so that soil fertility and soil moisture reserves are restored; and the availability of common property resources for cattle grazing. Thus, in the past, when population pressures were lower than they are now, a set of low input/output subsistence farming practices had evolved over time. Many of these options are no longer available to farmers.

THE FOOD OUTLOOK

Crosson and Anderson (1992) estimate that from now until the year 2030 the consumption of cereal grains in the world will increase by almost 100%, and that some 91% of this increase will be in developing countries (Table 1). This increase in consumption represents a growth rate of 2.3% per annum, is considerably less than the recent rate of growth in grain production in the developing countries, which grew at more than 3% from the mid-1960's to the late 1980's.

Coarse grains are estimated by Crosson and Anderson to have a rate of growth of consumption approaching 3.2% per annum in the period between 2005 and 2030. This is up from the figure they estimate for the period from now until 2005 of a consumption growth of 2.2% per annum. Most of this increase in consumption growth is attributable to the substantial increase in demand for coarse cereals derived from the growing demand for animal products. To contrast the 3.2% growth rate in consumption of coarse cereals from 2005 to 2030, they estimate that during the same period rice consumption will grow by only 1.3% per annum, and wheat by 2.3% per annum. Unfortunately they do not provide any estimates of demand growth for pulses and oilseeds.

The projections for coarse grains are worrying because unless production growth keeps pace we can expect to see an increase in the relative price of coarse grains resulting from the derived demand for animal products, and this could adversely affect the absolutely poor, who depend directly on these grains for food. Additionally, ensuring such increases in future production might entail unacceptable economic and environmental costs, which are described in detail by Crosson and Anderson.

A recent report (1991) by the Scientific Committee on the Application of Science to Agriculture, Forestry, and Aquaculture (CASAFA), of the International Council of Scientific Unions, suggests that total food consumption in the developing world would have to increase by approximately 3.5% per annum to the year 2030 for the population to achieve adequate nourishment. This far exceeds the estimate of 2.3% of Crosson and Anderson, which is based only on projections of demand growth resulting from income and population increases.

Crosson and Anderson examine whether the global agricultural system will be able to satisfy the growing demands for major foods to the year 2030 without unacceptable economic and environmental costs. They examine resources relating to land, water, plant genetic resources, climate, and knowledge about agricultural production systems embedded in people, institutions, and technology.

There are two possible sources of growth in longer-term food supplies. Firstly bringing more land under crop cultivation, and secondly expanding the area under irrigation.

With respect to the former Crosson and Anderson conclude that only some 25% of the 100% increase in global crop demand over the next four decades could be accommodated by bringing more land into crop production. Most future increases in global crop production must come from increased yields. They point out that their estimates are rather higher than the present consensus view on the subject.

Crosson and Anderson also point out that the economic costs and environmental risks of bringing more land under crop cultivation will be higher than the costs from land degradation associated with increased crop production on existing crop lands.

They also conclude it is unlikely that global supplies of irrigation water within the existing knowledge regime can be expanded enough to accommodate more than a small part of the increased demand for food represented in their demand scenario. This limitation is well illustrated by Stewart *et al.* (1991) who point out that the rate of growth of irrigated land in the developing world was 4.5% per annum from 1950 to 1960 (Table 2). It declined to 3.5% in the next decade, and then to 2.1% per annum from 1970-1985. Currently they estimate irrigated land is growing by less than 1% per annum.

The continuing emphasis on irrigated agriculture is based on the perception of its potential relative to rainfed agriculture. Almost all projections of future agricultural growth in Asia count heavily on a continued contribution from irrigation. Gasser (1981) estimated that in Asia more than 75% of the increase in food supplies through the end of this Century will come from irrigated lands, which currently represent about 30% of the total cultivated area.

These estimates are based on perceptions which may have been valid a decade ago. Today it is clear that many of these high production, intensively cultivated, irrigated systems are under threat from problems of salinity, waterlogging, and pollution. The burden of meeting the world's future demand for cereal consumption will not and cannot come solely from irrigated areas.

SOME CONTRIBUTIONS FROM ICRISAT

ICRISAT celebrates its 20th Anniversary this year. Since its inception 166 improved cultivars of our mandate crops have been released in 48 countries. These were developed in collaboration with our national program partners.

Sixty-eight of these releases were in Asia, 34 in sub-Saharan Africa, 28 in West Asia and North Africa, and 21 in Latin America and the Carribean. Fifteen releases were in developed countries. ICRISAT is clearly an INTERNATIONAL center.

The pattern of releases shows that it took on average 5 years to the first release of cereal cultivars from ICRISAT-derived material, and 11 years for the legumes. This illustrates that ICRISAT had a greater body of accumulated scientific knowledge to build on when it began in 1972 in the case of cereals than in legumes.. In spite of this there have been a total of 95 releases of our legumes and 71 of our cereals. Details of releases are given in Appendix Table 1, their distribution access, regions is shown in Figure 1.

Let us provide a few specific examples of technology options which have emerged from our research in recent years.

Sorghum

The midge-resistant sorghum varieties ICSV 743 and ICSV 745 have been adopted by farmers in Karnataka and Tamil Nadu in India. These lines yield 3-5 times more than the commercial hybrids in midge-endemic areas.

In 1987, a sorghum variety developed at ICRISAT Center, ICSV 88060, was tested and released in Zimbabwe as SV 2. In the 1992/93 season, an estimated 150,000 ha in Zimbabwe and over 35,000 ha in Mozambique will be sown to this variety. Although released in 1987, sufficient breeders' seed of the variety was not available for multiplication to meet the demands of farmers until 1990, when sufficient seed was multiplied by the Zimbabwe Seed Cooperative. In 1992, 438 ha of off-season plots were grown to this variety for seed multiplication. Seeds of SV 2 are being exported to Mozambique, where it is being multiplied by SEMOC, the national seed company, although the variety is not yet officially released in that country. In Mozambique, there was a demand for 750 t of seed of SV 2, while SEMOC was only able to produce 300 t.

Another ICRISAT variety, Tegemeo (2KX 17), is expected to be sown on over 11,000 ha in Tanzania in the 1992/93 season. The slow adoption of this material has been attributed to the lack of good quality seed. Last year, in the Dodoma region of Tanzania, there was a demand for 46 t of seed of Tegemeo even though 75% of the farmers growing white sorghum in this region were already growing Tegemeo. The national seed company Tanseed, with the help of Sasakawa Global 2000, was able to provide only 20.9 t. Under high inputs and good management, Tegemeo yielded 2-4 t/ha in Tanzania under the Farmers in Management Training Plots scheme of Sasakawa Global 2000. With the application of seed-dressing and fertilizer, ordinary farmers in Tanzania were able to procure seed yields ranging between 1 t/ha and 4 t/ha.

Yet another achievement of SMIP's sorghum breeding is the sorghum variety SDS 2302-1, released in Zambia in 1989 as Kuyuma or WSV 387. Although the variety has not been released in Mozambique, its release in Zambia has sparked an interest for it in Mozambique. Once again adoption of this released variety was hampered by the shortage of seed. SMIP, with the help of USAID, grew 156.5 ha of the variety in 1992 on off-season plots. This seed is expected to be sown on 50 000 ha in Zambia, 10 000 ha in Mozambique, and 40 000 in Malawi.

The annual value of the new income streams generated from the adoption of the above three improved sorghum cultivars in the SADC region are estimated to currently exceed US$ 7 million.

Pearl Millet

Based on data from breeders' seed supplied to public and private seed companies, the area under ICRISAT pearl millet downy mildew resistant cultivars in India in 1991 was estimated to be about 1,000,000 ha of ICMV 1 (WC-C75), 1,500,000 ha of ICMH 451, and 800,000 ha of ICTP 8203. The commercial value of the increased production from these cultivars was estimated at US$ 54 million in 1991. It is estimated that ICMV 1 alone has contributed at least US$ 17 million per annum to Indian agriculture since 1987.

The variety ICMV 84400, released as ICMV 155 in India in 1991 is resistant to downy mildew and consistently yields 12% more grain and 9% more fodder than ICMV 1. It has replaced ICMV 1 at several locations. During 1992 we distributed 65 kg of breeder seed of ICMV 155 and 37 kg of ICMV 1 to public- and private-sector seed-production agencies in India. This reflects the increased demand for ICMV 155, as for the first time in India since the 1960's, farmers have an alternative choice before a widely cultivated pearl millet variety, or one of its parental lines, succumbs to downy mildew.

The pearl millet variety SDMV 89004, released as PMV 2 in Zimbabwe, is the first pearl millet variety developed by the Southern African Development

Community (SADC)/ICRISAT Sorghum and Millets Improvement Program (SMIP) to be released in that country in the coming season. It is high-yielding and early-maturing, and is ideal for the short season and frequent droughts that lead to crop failure in most of the communal areas where the crop is grown. PMV 2 is expected to be sown on more than 90,000 ha in Zimbabwe alone. The variety is also in on-farm trials in Namibia and Botswana. Although not yet officially released in Malawi, PMV 2 is expected to be sown on another 15,000 ha in that country.

The SADC/ICRISAT successes are not limited to this one variety; other ICRISAT material has also reached farmers' fields in southern Africa. The earliest releases were in 1987, just 4 years after SMIP was established. Five years later more than double the number of such materials have been released for cultivation by the national agricultural research systems (NARS) in the region. In the coming years, more and more of such materials will reach the farmers' fields and their impact will be increasingly visible in another 5 years. Releases by country in the SADC region are shown in Appendix Table 2.

In 1991, SADC/ICRISAT SMIP made a significant contribution to the well-being of farmers and consumers in northern Namibia when seed of high-yielding ICRISAT pearl millet varieties began to reach farmers in significant quantities. The SMIP increased 10.5 t of Okashana 1 (originally ICTP 8203, now ICMV 88908) seed during the 1990 winter at its off-season location at Mzarabani, Zimbabwe, and sent it to Namibia where it was sold to farmers. During the 1990/91 season, in northern Namibia, 30 t of seed were produced and approximately 20 t sold to 10,000 farmers. The quantity distributed was sufficient to sow some 5,000 ha in 1991/92, a season characterized by severe drought. Nevertheless, ICRISAT scientists estimate that Okashana 1 doubled the local pearl millet yields of 200 kg/ha. The resulting 1000 t of additional grain will contribute over US$ 900,000 worth of additional income during the 1993 harvest.

This is yet another example of global movement of germplasm facilitated by ICRISAT. The base material of Okashana 1 was collected from Togo, western Africa and developed at ICRISAT Center in India. It is expected to be grown on 40,000 ha of farmers' fields in Namibia, and will soon also be growing in farmers' fields in neighbouring Angola.

The total new annual income streams from both these pearl millet releases in SADC countries are currently estimated at US$ 3.7 million. Most of this money will accrue to the poorest segments of the countries concerned.

Chickpea

Recently six kabuli chickpea cultivars, developed by the ICRISAT/International Center for Agricultural Research for the Dry Areas (ICARDA) Kabuli Chickpea Project based at ICARDA, Syria have been released: FLIP 83-48C and FLIP 84-92C in Morocco; FLIP 81-293C as Noor 91 in Pakistan; and FLIP 82-259C, FLIP 85-14C, and FLIP 85-60C in Turkey. All these cultivars have resistance to ascochyta blight. Morocco and Turkey have released them for winter sowings where the crop is normally spring-sown. Adoption of winter chickpea in the Mediterranean region has increased from 10,000 ha in 1990/91 to more than 30,000 ha in 1991/92. The significance of winter-sown chickpea is that it enables a legume crop to fit into cereal rotations in such areas as northern India and Pakistan and eastern Europe. It provides a protein-rich additional crop, and improves the soil's nitrogen status, thus helping to improve the sustainability of the cropping system.

Two ICRISAT chickpea varieties, ICCV 2 and ICCV 37 were released in 1989 in Andhra Pradesh. ICCV 2 is the first kabuli type with resistance to fusarium wilt to be released for cultivation in peninsular India, and yields more than 1 t ha^{-1} on residual soil moisture in the postrainy season. It is also popular in Maharashtra. These two varieties are being cultivated on about 50,000 ha in India.

Pigeonpea

The area under short-duration pigeonpea in India has increased with the release of ICRISAT short-duration varieties, ICPL 87 and ICPL 151. The present area of short-duration pigeonpea in India is estimated to be approximately 100,000 ha, ICPL 87 being the most popular cultivar, particularly in the states of Maharashtra and Gujarat. Short-duration pigeonpeas have advantages over traditionally cultivated long-duration types because their growth and maturity durations match the period of soil moisture availability in rainfed conditions. They yield well, can escape terminal drought stress, and are better adapted to several cropping systems.

The ICRISAT pigeonpea ICPH 8, the world's first hybrid pigeonpea was released in July 1991 in central and peninsular India. It yields 30 to 40% more than conventional open-pollinated cultivated varieties. The release of this hybrid is a landmark in our efforts to improve global pigeonpea production. Following the release and the workshop on pigeonpea hybrid seed production technology that ICRISAT organized in 1991, private- and public-sector seed companies have shown keen interest in the technology. During 1992, we distributed parental seed of ICPH 8 to 13 seed companies and one research organization in India. A leading private seed company, Maharashtra Hybrid Seeds Company (MAHYCO), in Maharashtra, India is already marketing the seed of ICPH 8.

We are making good progress in the Pigeonpea Production Project in Sri Lanka where we jointly collaborate with the Asian Development Bank and the Department of Agriculture, Sri Lanka, to improve the crop production in the dryland areas of Sri Lanka. An indication of this was apparent when the Sri Lankan Minister for Agriculture encouraged the Project to consider achieving a dramatic increase in sown area (from 70 ha to 4000 ha). As this was not immediately realizable because of a shortage of seed, the actual increase was a modest 200 ha, sufficient to allow an orderly establishment of plots and of dhal-processing facilities. The production system appears to be economically very attractive. The ICRISAT line ICPL 84045 was identified as a replacement for ICPL 2 in Sri Lanka. The rekindling of interest in pigeonpea should help to reduce costing imports of lentils that are presently used to make *dhal* in Sri Lanka. Pigeonpeas, have been tried and tasted by the local people and found to be a highly acceptable substitute.

Groundnut

Nine ICRISAT groundnut varieties have been released for cultivation in India. Three of these varieties, ICGS 11, ICGS 76, and ICGS 44, occupy about 60,000 ha.

In 1987, the Indian Ministry of Agriculture sought collaboration with ICRISAT to help in extending improved groundnut, pigeonepa, and chickpea production technologies to farmers. Accordingly, ICRISAT formed the Legumes On-Farm Testing and Nursery (LEGOFTEN) Unit and, in collaboration with the State Departments of Agriculture, conducted many on-farm trials to demonstrate the yield potential of improved and local varieties using improved and local packages of production practices. The improved packages generally involved growing the crop on raised beds, treating the seeds with fungicide, using an adequate seed rate, applying optimum doses of appropriate fertilizers, irrigating it at critical stages, and applying pesticides at the right time. The impact of these packages is well illustrated by groundnut. Several groundnut on-farm trials were conducted between 1987 and 1990. In these trials, the improved package of production packages gave around 25% more yield than the local package, and improved varieties around 30% more yield than local varieties. Taken together the improved package plus the improved varieties proved to be about 60% more productive than the local package and varieties. Though improved technology (package + variety) required an additional expenditure of about US$ 50 it gave an average increased income of US$ 195/ha above that of the local technology.

Among various components of the improved package, growing the crop on raised beds appeared promising but needed more supporting evidence. Thus, ICRISAT in collaboration with the Directorate of Oilseeds Research (DOR), India, conducted a series of groundnut trials to compare the value of the raised bed with the flat bed. These trials, conducted between 1989 and 1991, indicated that the raised bed had about 14% yield benefit over the flat. Based on these results, the use of raised beds for growing groundnut has been recommended in India.

There were many other demonstrations in farmers' fields, and these produced similar results to the on-farm trials. This led to rapid adoption of the improved groundnut technology by farmers since it has been backed by committed support from the State Cooperative Oilseeds Growers' Federations (SCOGFs) which are funded by the National Dairy Development Board (NDDB). From 1989, the NDDB has made an annual allocation of US$ 0.15 million to each SCOGF for a period of 5 years towards the spread of this improved groundnut production technology to Indian farmers.

During the course of LEGOFTEN on-farm trials and demonstrations, various new ideas were developed and innovations made to improve technology adoption by farmers. The Indian Ministry of Agriculture and the Indian Council of Agricultural Research (ICAR) which were the recipients, and the International Fund for Agricultural Development (IFAD), which was the funding agency, assessed the impact of the LEGOFTEN project on its conclusion in Dec 1991. They observed tangible gains in the production of groundnut, pigeonpea, and chickpea at on-farm levels, and in the assimilation of the on-farm research and transfer of technology methodologies in the national institutions. They appreciated the project achievement in linking the groundnut production technology to the oilseeds development program of the NDDB which has a notable record of success in the dairy industry. They also expressed satisfaction over the performance of ICRISAT's improved varieties and crop management options.

Seed Supplies

Because of the historical neglect of rainfed agriculture and of the "orphan" crops in ICRISAT's mandate, many of the improved cultivars developed from ICRISAT's materials languish for want of production and distribution of certified quality seed. A recent analysis by Singh *et al.* (1990) indicates that the gap between seed demand and supply in India for groundnut amounts to more than 80%. For sorghum the excess demand is about 50% and for millet more than 25%. The World Bank and the regional banks should persist with their lending programs in support of the seed sector in developing countries, in spite of some of the past disappointments. We in ICRISAT experience genuine difficulties in ensuring that our improved materials find their way to farmers' fields. We have been prepared to provide breeders' seed and help train public and private sector staff in seed production, but we of course, cannot take major responsibility for commercial seed production.

Sandy Soils of the Sahel

In the Sahel, rainfall is variable and undependable. The major soils are generally sandy in texture. For example, the sand fraction of soils in Niger usually exceed 92%. The soil reaction is slightly to strongly acidic and exchangeable aluminium can exceed 50% of the cation-exchange capacity in some soils. Average water-holding capacity varies, depending upon the depth, from 75 to 150 mm. Poor fertility is a major problem in Sahelian soils; their organic matter content rarely exceeds 0.3%. The poor structural stability of these soils is a major constraint since they are susceptible to wind erosion when dry. Under traditional farming conditions, average grain yields of pearl millet are very low, ranging from 130 to 285 kg/ha (Spencer and Sivakumar, 1987).

The above conditions have led to a popular myth that Sahel means unproductive, dry sand. However, research has shown that increasing crop yields under these conditions is based largely on an improved understanding and judicious utilization of the soil and climatic resources.

From the studies on soil physical, chemical, and hydraulic properties carried out by Hoogmoed and Klaij (1990), a clear understanding of the soils and their limitations emerges as follows:

- The soils have a very low fertility status and a rapid decline in productivity could occur under conditions of continuous cropping without the addition of organic or inorganic nutrients.

- Infiltration and redistribution of rainfall on these soils is very rapid, and runoff losses are generally low.

- Mechanical treatment is effective only when the soil is moist.

- The high rates of soil evaporation, especially from rains that fall at the beginning of the season, demand rapid land preparation for, and efficient methods of sowing.

Climatic Data Analysis Used to Derive Effective Cropping Strategies in the Sahel

Prediction of rainy-season potential. In view of the large rainfall variability, reliance on monthly and annual rainfall totals is of little value in deriving effective cropping strategies. Parameters such as the onset and ending of rains and the length of the growing season are important for decision making. From a study of these parameters, Sivakumar (1988) showed that it is possible to predict the rainy season potential in the Sahelian zone from the date of onset of rains. This is based on the finding that the onset of rains is much more variable than the ending of rains. Therefore, an early onset of rains offers the probability of a longer growing season, while delayed onset results in a considerably shorter growing season. Hence, the potential of the growing season can be assessed with reference to the date of onset of rains. In Niamey, Niger if the onset of rains occurs 20 days early (i.e., by 24 May) there is a 71% probability that the growing season will exceed 120 days (Table 3). On the other hand, if rains are delayed until the beginning of July, there is only a slight probability of the growing season exceeding 100 days.

Analysis of the nature of intra-seasonal droughts. Although the date of onset rains provides a clue to the potential of the growing season, uncertainties still abound as to rainfall distribution within the growing season. The major concerns are; when droughts are most likely to occur within the growing season, and what the expected length of such droughts would be. Long-term daily rainfall data can be analyzed to answer such questions. Sivakumar (1992) used a specific definition of onset of rains for each year as the sowing date and computed the length of dry spells (or days until the next day with rainfall greater than a defined threshold value) and the percentage frequencies of dry-spell lengths. This analysis showed that in the Sahel, dry spells from the stage of emergence to panicle initiation (up to 20 days after sowing) of pearl millet last longer than those during panicle initiation to flowering (20-60 days after sowing). The implication of this analysis for soil management is that conservation of soil moisture in the establishment phase of the crop is critical.

Rainfall analysis for preparatory tillage. In view of the short season and the farmer's limited capacity in terms of available power, the number of days available for preparatory tillage prior to the optimum date of sowing is an important issue. Hoogmoed (1986) concluded that the size of rainfall showers relevant for decision making with regard to preparatory tillage is fairly predictable, and that one could calculate the total number of days available for preparatory tillage and sowing. In Niamey, Hoogmoed and Klaij (1990) showed that the total number of workable days is 31 and the average number of plantable days does not exceed 10. This analysis shows that the speed with which planting operations can be carried out is an important issue. Other studies at ISC have shown that animal traction using simple donkey-drawn implements developed at ISC offers good possibilities for reducing the time taken to prepare land for sowing.

Deep Vertisols of India and Africa

Vertisols are dark-colored clayey soils that are found under varied climatic conditions covering about 310 million ha worldwide (Dudal, 1965). In Asia they cover much of India (70 m ha) and parts of Myanmar (Burma) and Thailand. Several countries in Africa and Latin America have Vertisols and soils with vertic properties. In the tropical countries, increasing the productivity of these soils presents serious problems of land and water management. During the dry season, these soils crack, and these cracks may be 5 to 20 cm wide and 30 to 50 cm in deep. Therefore, preparation of the seedbed is difficult until the onset of the rainy season. Once the rainy season sets in, the soils present traffic problems for land preparation. It is difficult to maintain their surface configuration and since their terminal infiltration rates are extremely low, waterlogging during the rainy season is common.

Due to these constraints, a popular myth prevailed in India that Vertisols cannot be cropped in the rainy season and the prevailing practice was to leave the soils fallow in the rainy season and crop them only in the postrainy season. Hence, the productivity of these soils remained generally low; for example on the Deccan plateau of India the average sorghum yield is only about 700 kg/ha.

Vertisols of the semi-arid tropics, however, have a fairly high potential for crop production that remains to be realized. The case study of Vertisols is illustrated primarily from the studies conducted at the ICRISAT Center which shows that through an understanding of climate and the application of the science and technology of land, water, and crop management, Vertisols can be cropped in the rainy season and can be made productive.

Land and water management. Improved land and water management practices are applied to alleviate such constraints as waterlogging. Under the improved system of management, 3 to 15 ha microwatersheds size are used as units for land and water management and agronomic practices. Surface drainage is improved through the provision of surface drains and land smoothing. The *in-situ* water conservation improvements are brought about by laying out broadbed-and-furrow (ridge-furrow) cultivation systems along the contours. Since the surface runoff water is discharged in a controlled manner, the loss of soil is considerably reduced and water-use efficiency is considerably increased. At ICRISAT Center, the main features of this system are that on a slope of 0.4 to 0.6% graded broadbeds and furrows (150-cm apart) are made that leading into grassed waterways and finally into a dug tank or drain. By following this system, soil moisture storage is increased, and the drainage of excess water is facilitated.

Primary tillage to prepare a rough seedbed is best carried out soon after the harvest of the previous crop. Land should be harrowed whenever 20 to 25 mm of rain is received over a period of 1-2 days. When blade harrowing is done, the clods easily shatter and a satisfactory seedbed is attained.

This technology is now finding wide applications. An ICRISAT scientist is based in Ethiopia at the International Livestock Centre for Africa (ILCA) to work on a Joint Vertisol Project in cooperation and the International Board for Soil Research and Management (IBSRAM) with the scientists of Ethiopia's Institute for Agricultural Research, Alemaya University of Agriculture (AUA), and ILCA. The objective of this collaborative work is to develop Vertisol watersheds at sites near Addis Ababa. We are conducting research on farms to develop strategies and technology options to raise and sustain crop and livestock production on Vertisols. Our observations to date indicate that Vertisol fields generally have several microdepressions that exacerbate the waterlogging problem. The observations at Debre Zeit and Ginchi have shown that wheat yields per unit area were 58% to 75% lower in depressed areas (maximum depth 15 cm) than in the smooth portions of the fields. The positive effect of broaded-and-furrow treatments on wheat yields was observed only in the smooth portions of the field and not in the microdepressions. Land smoothing is obviously a crucial operation that is necessary if the drainage on these soils is to be improved.

Dry sowing ahead of onset of rainy season. Since the preparation of the seedbed and the sowing of crops present serious problems in Vertisols, sowing crops in dry soils ahead of the commencement of rains was found to ensure early establishment, and to avoid the difficulties associated with sowing in a wet, sticky soil. Dry seeding is successful where the early season rainfall is fairly dependable and when seeds are placed at a depth of 7 to 10 cm. At ICRISAT Center, good stands were established by dry seeding of crops such as mungbean, sunflower, maize, sorghum, and pigeonpea.

Improved cropping systems. The adoption of improved cropping systems provides a continuum of crop growth from the commencement of the rainy season until most of the available moisture is used by the crop. At ICRISAT Center this was achieved by:

i) Intercropping long-duration crops (e.g., pigeonpea) with short-duration crops (e.g., maize, sorghum, or soybean).

ii) Sequential cropping (e.g., sorghum or maize followed by chickpea or safflower).

Fertility management. In the tropics, the management of soil fertility is important if the full potential of improved cropping systems is to be realized. At ICRISAT Center, effective management of soil and fertilizer nitrogen was found to be a necessary ingredient for improved productivity in Vertisols. The application of phosphates and zinc was also found to be essential. Inclusion of legumes in the crop rotations or in intercropping systems substantially reduced the fertilizer-N needs (by about 40 kg of N/ha) of the subsequent cereal crops.

Efficient farm machinery. For a successful implementation of an improved Vertisols management system, it is necessary to carry out all the operations thoroughly and in good time. Since animal draught is the main source of energy available to small-farm operators of semi-arid areas in Asia and Africa, ICRISAT has paid attention to the development of several types of animal-drawn equipment. The use of a wheeled tool carrier (e.g., Tropicultor or Nikart) was found to be an efficient technique for managing Vertisols in India, and the donkey-drawn Hata is also proving its potential in western Africa.

Appropriate crop management. To realize the full potential of improved land and water management and cropping systems, it is essential that an appropriate set of crop management practices be adopted. Weed control, integrated pest management, the placement of fertilizers at an appropriate depth and their application at critical stages of crop growth are some of factors that could lead to the realization of high and sustained yields on Vertisols.

One important aspect of the improved Vertisol technology options is the synergistic effect of various components when applied together, as compared with their individual effect. This point has been brought out convincingly after 13 years of watershed-based experimental results from ICRISAT Center (Table 4). Kanwar and Rego (1983) and Kanwar *et al.* (1982) noted from research on components of Vertisol technology options conducted at ICRISAT Center, that although the contribution of fertilizers was highest, the response to fertilizers was most enhanced when they were applied in combination with improved land and water management treatments, and the adoption of improved agronomic practices. This observation has great relevance in the African continent. Here fertilizers are costly and often have to be imported. Therefore, all efforts must be made to realize maximum fertilizer use efficiency by applying the principles of improved Vertisol technology.

At ISC work in collaboration with the International Fertilizer Development Center (IFDC) has shown that local rock phosphate deposits if partially acidulated, offer a potentially cheaper source of phosphorus that could be used to good effect on Sahelian crops.

Improved productivity. Using the above components of technology it was possible to grow two crops, one in the rainy season and another in the postrainy season, and considerable increases in crop production resulted (Virmani *et al.*, 1989). Where a farmer harvested about 0.6 t/ha of sorghum or 0.9 t/ha of chickpea by using his traditional system, a total yield of about 3 t of grain/ha has been consistently harvested through a two-crop combination under an improved Vertisols management system at ICRISAT Center during 1976-89 (Table 4). Further, in the vertic soils several intercrop combinations (e.g., sorghum/pigeonpea or millet/pigeonpea) have produced yields of 2 to 3 t/ha under a medium fertility treatment (Table 5). The introduction of the new system also has resulted in: (a) a considerable reduction in soil erosion; (b) much higher *in-situ* moisture conservation, and therefore in higher rainfall-use efficiency (Table 6); and (c) more dependable harvests year after year (Table 4).

A CRITIQUE OF RAINFED RESEARCH

Dhawan (1991) recently raised questions about the relative lack of progress in productivity growth in rainfed areas of India.

"If modern rainfed farming is not making its mark in such a state [Andhra Pradesh] with rather favorable conditions for success of rainfed technology, it is not a very encouraging situation to warrant a major dependence on rainfed farming option to meet our rising needs of food, fibre and fodder". This is Dhawan's indictment of rainfed farming; and it is not altogether valid. There are three major problems with his conclusion, particularly the implicit indictment against ICRISAT.

Firstly, Dhawan reports that for Andhra Pradesh not a single crop under rainfed conditions exhibited an upward trend in yield during 1972-87. In fact, under nonirrigated conditions, pearl millet--an ICRISAT mandate crop--had a positive and significant growth rate in yield per hectare. Sorghum, also had positive but non-significant growth rates in yield per hectare (2.5 in the rainy season and 1.3% in the postrainy season). While no separate figures are given for pigeonpea and chickpea, pulses--used as a proxy-- also registered a positive but non-significant growth rate in yield (1.9%). Thus, both ICRISAT's cereal and pulse crops had positive growth rates.

Furthermore, an analysis of absolute percentage changes in yield per hectare during this 15-year period (1972-87) shows substantial increases in productivity for all of ICRISAT's mandate crops. Increases in yield per hectare between 1971-73 (three-year average) and 1986-88 in Andhra Pradesh were 27% pearl millet, 32% for sorghum, 66% for pulses, and 12% for groundnut.

Secondly, Dhawan's analysis is limited to Andhra Pradesh but his conclusions are supposedly relevant for all rainfed farming areas of India. ICRISAT has a geographical mandate which reaches far beyond Andhra Pradesh. This selective case study ignores many notable achievements realized in other states and regions, both inside and outside India. A similar analysis of Maharashtra would reveal a different result, and tell a different story. The absolute increase in yield per hectare of sorghum between 1972 and 1987 was more than 100% for that state, with an annual growth rate of 5.6%. In many districts the increase was much higher. Credit rightfully belongs to ICRISAT, the Indian Council of Agricultural Research (ICAR), and the private sector for their work in developing high-yielding cultivars well-adapted to this area. The development, release, and adoption of high-yielding cultivars of pearl millet in Gujarat, eastern Rajasthan, northwestern Maharashtra, and Karnataka, where significant increases in productivity were realized, is another example of demonstrated research success by ICRISAT working in collaboration with ICAR. We would concede to Dhawan, however, that ICRISAT and ICAR achievements have been less than satisfactory in the southern states of Andhra Pradesh, Karnataka, and Tamil Nadu, particularly in the more difficult environments within those states.

Thirdly, positive changes in yields per hectare of rainfed crops in Andhra Pradesh were realized despite several factors exerting a negative effective on state average yields. The area under pigeonpea and other rainfed crops declined between 1972 and 1987. These crops were mainly replaced by cotton and castor, and to some extent by postrainy-season groundnut. While there is no hard evidence to support this, it is reasonable to assume that sorghum, pearl millet, and pigeonpea lost ground in the relatively more favorably endowed areas, and thus, average yields in 1987 were more greatly influenced by data from low-yielding areas. The substitute crops are less well adapted to the marginal environments in which sorghum, pearl millet, and pigeonpea seem to predominate. It is perhaps more important to note that the area under irrigated crops significantly increased during this period. This was presumably accompanied by a shift in such resources as fertilizers and labor away from rainfed crops toward the more profitable (and more resource-use efficient) irrigated fields. Motavalli (personal communication) showed recently that farmers allocate only about 20% of their total farmyard manure to nonirrigated fields. Shifting resources and inputs away from rainfed crops and fields would obviously have a serious impact on yield growth rates of rainfed crops. It would be nice to test this hypothesis and determine the extent to which this may account for the sluggish growth in rainfed crop yields compared to those of irrigated crops. But we should not delude ourselves by expecting growth in rainfed crop yields to rival growth in yields for irrigated crops. The challenge for us is far greater; incremental gains will, and should be, valued much more highly.

ICRISAT considers that the heterogeneity and harshness of the semi-arid tropics means that we are likely to see numerous "green evolutions" rather than one highly visible "green revolution", as with rice and wheat. Greater visibility of the impact of improved cultivars in rainfed agriculture will only occur if they are adopted along with complementary improvements such as soil, water, and fertility management. All these elements are more location-specific than is irrigated agriculture and hence deserve greater and not less agricultural research and development (R&D) investments.

PRODUCTIVITY AND SUSTAINABILITY: DICHOTOMY OR NEXUS?

There are some eight environmental and sustainability concerns which are commanding the attention of the international community. These are; global warming, deforestation, soil erosion, chemical pollution, biological diversity and conservation, policies inimical to sustainability, excessive population growth, and poverty. Many of these are recognized as being interrelated and involving uncertain lines of casuality.

One of the basic questions we need to address is the extent to which research aimed at increasing agricultural productivity in the near term involves a trade-off in the achievement of productivity gains at some time further into the future. This is illustrated in Figure 2 which includes four possible sustainability relationships.

On the vertical axis productivity gains at some long-term future time t + n, are represented, and on the horizontal axis productivity gains in the near term, i.e., at time t. Land degradation could be represented by the relationship in the lower left-hand corner of the graph, whereby in the attempt to achieve gains in productivity in the short term it is found that very quickly, not only does it entail a trade-off in productivity at some time well into the future, but in endeavoring to proceed further, productivity both today and tomorrow has to be sacrificed. An unsustainable R&D strategy entails a trade-off between productivity today and tomorrow. A sustainable one implies that productivity gains can be achieved today without sacrificing productivity gains some time in the future. Environmental nirvana is represented by the top relationship whereby one can achieve productivity gains both today and tomorrow from environmentally friendly R&D programs. The technology options related to the management of Vertisols in assured rainfall areas is one example of potentially environmentally friendly relationships, at least from the aspect of soil erosion. However, we have recently found that the soil biology may change after many years in ways which may mean that even here we are facing only at best a sustainable relationship.

One of the essential points here is that not only does it require long-term R&D activities to define these types of relationships, but that one's degrees of freedom may be somewhat constrained in designing environmentally friendly technologies.

To my mind many, if not most, environmental choices are often about intergenerational equity. Costs, benefits, and trade-offs are all involved, and decisions based on imperfect information about these are the rule rather than the exception, especially when it comes to defining agricultural research portfolios. This was evident to all of us in the recent medium term planning exercise at ICRISAT.

Both Norse (1992) and CASAFA (1991) believe there are very real trade-offs between concerns for the environment and the need for development. Norse says that many small farmers are forced to use unsustainable agricultural practices for a variety of institutional and economic reasons. In their struggle to satisfy current food needs they have to place at risk the long-term carrying capacity of their land. Fine ecological words and appeals on behalf of future generations will not sway them unless the required changes in land management practices will also raise present-day household security. CASAFA point out that comparatively few who write and recommend low-input, more labor-intensive production systems appear to be developing-country farmers. Significant change can impose significant risk; risk that is borne by farmers. To reduce risk, changes to established production systems should be based on sound research and thorough on-farm evaluation.

Under stressed conditions CASAFA indicates that food security demands may conflict with ecologically desirable production systems. Poor people in urgent need of food and fuel will not give first priority to soil and forest conservation. Where farm land and other resources are strained by high population sustainable production and distribution are not easily conceived. A compromise must be reached between urgent demands and ecological ideals. Idealists whose survival and welfare are not at risk should consider those less fortunate, according to CASAFA.

Vyas (1991) says that it is not small farmers and the poor that degrade the environment but rather the agrarian structures that skew land and wealth distributions. He contends that it is the lifestyle of the rich rather than the petty pilferage of the poor which contributes to the pressures on land and natural resources in the developing world. This view is at variance with that of Norse and Vosti *et al.* (1991) of International Food Policy Research Institute (IFPRI). The latter indicate that global and national environmental concerns are often incompatible with smallholder farmers' goals of increasing their incomes and feeding their families. They contend that most environmentally destructive activities in the developing world are the work of smallholder farmers seeking to eke out a living. These activities are guided by government policies but are dominated by the farmers' short-term objective of feeding their families. Solutions to sustainable management of the natural resource base must include sustainable agricultural development and poverty alleviation. Gaining a better understanding of the inter-relationships between these objectives will ensure solutions that will themselves be sustainable.

The enormous task of avoiding massive malnutrition and starvation in the near term requires choices that focus on this problem, even at the expense of long-term environmental sustainability. CASAFA believes that implementation of the policies which may suit the wealthy minority could be disastrous for the poor majority. There is no historical record of agricultural production increasing by 3.5% in a single year, yet this is the growth rate needed for at least 40 years if people are to be adequately nourished. The magnitude of this task may elude the imagination of people mainly concerned with the ecological stress caused by over-subsidized agriculture in nations whose survival and self-sufficiency are not at risk.

MARGINAL VERSUS FAVORABLE ENVIRONMENTS: EFFICIENCY AND EQUITY CONSIDERATIONS

The recent draft paper of the Consultative Group on International Agricultural Research (CGIAR) Secretariat entitled "CGIAR support to implementation of the UNCED Agenda 21 recommendations" points out that there is a special challenge in enhancing the performance of marginal lands. They classify these lands as those with erratic or excessive rainfall, poor soils, steep slopes, or inadequate drainage. The paper suggests increasing the emphasis on developing crop varieties that; withstand drought stress, are to poor soils; resist disease and pest attack; and, in highland areas, tolerate cold. Marginal environments call for deployment of a range of practices that serve as insurance against late rains, lower than normal rainfall, or pest and disease epidemics. It involves diversification of cropping as well as utilization of several varieties of each crop, each with different nutrient requirements and tolerances for environmental stresses. Farmers on marginal lands generally have fewer resources such as access to irrigation and pesticides to combat challenges. Genetic resistance or tolerance for environmental stresses, according to the CGIAR, is not especially important in these marginal areas.

Does a focus on the more marginal environments in the semi-arid tropics necessarily imply a trade-off between the poverty focus of ICRISAT and those goals related to socioeconomic impact and sustainability? Some preliminary data analysis provided to me by Dr Kelley and his colleagues in the Economics Group of the Resource Management Program at ICRISAT Center provide some interesting contrasts in this respect (Table 7).

If we divide the semi-arid tropical regions of India into the less-assured and more-assured regions on the basis of rainfall and soil type, we find that there are about the same numbers of absolutely poor people in both regions, i.e., approximately 50 million. The less-assured zones are those with less than 1,000 mm annual average rainfall, with sandy Alfisols, vertic soils, and sandy soils, in addition to those with sandy soils and Vertisols with less than 750 mm average annual rainfall. The assured zones were defined as those with Vertisols and Inceptisols with more than 750 mm average annual rainfall, as well as the sandy Alfisols, vertic soils, sandy soils, and deep Alfisols with more than a 1000 mm average annual rainfall.

As a proxy for expected socioeconomic impact, the total value of agricultural production has been calculated for the two zones. For the less-assured, semi-arid tropical regions of India, the gross value of agricultural production for the 14 most important crops amounted to just over US$ 10 billion per annum. In contrast, the more assured regions had only about 10% higher gross value of agricultural production, at US$ 11 billion per annum.

Using this method of characterizing marginal from assured environments in India suggests that there may not be a necessary trade-off between poverty and socio-economic impact on *a priori* grounds. Of course, there may be considerable differences in the likelihoods of success of research focussed on these contrasting environments from the aspect of productivity gains, as well as in terms of adoption potentials and expected increments to crop yields.

The yields of the ICRISAT mandate crops are higher in the assured-rainfall areas of India, but these areas represent a much smaller share of the total cropped area (19%) than is the case in the less-assured areas (44%). Interestingly, the yields of rice, cotton, finger millet, rape, mustard, sunflower, and safflower are all higher in the less-assured areas compared to the more-assured. However, this may be due to the fact that the classification scheme used includes sandy Alfisols in the 750-1000 mm rainfall zone as a part of the less-assured environment.

What these preliminary figures suggest is the need for us to utilize our geographic information system (GIS) to more accurately characterize our semi-arid tropical environments, and thus to enable us to better target our research and build on the momentum of our medium term planning exercise.

If, on further analysis, it is confirmed that there are agro-ecological regions where our crops represent both a higher percentage of the total cropped area and gross value of production, this would mean there are few alternative suppliers of new income streams and employment opportunities for the poor people residing within them. If in addition, the absolute dollar contribution of our mandate crops to gross value of production is large and there are a large number of absolutely poor people residing in the zone, then by these criteria the region should receive priority, other things being equal.

In another preliminary analysis Kelley and his colleagues have found for India a weak invérse relationship between the proportion of a state classified as marginal (based upon the extent of land producing less than Rs 750 (US$25) gross value per hectare), and the absolute numbers of rural poor in that state (Figure 3). If this type of relationship stands up to further analysis and is shown to be more general, it suggests that there may not be a necessary trade-off between an emphasis on the more-assured zones, with presumably greater potential productivity gains, and the generation of benefits to the poor.

Are there trade-offs to be confronted when it comes to setting priorities for sustainability research?

According to Stewart *et al.* (1991) the hot and dry environments are those where the achievement of sustainability is much more difficult than in the cooler and wetter environments. The reasons are that degradation processes such as soil erosion and fertility declines are accelerated in the more arid and hotter climates. Additionally the benefits from soil conservation are lessened in these hot dry environments. They state that Alfisols are more vulnerable to erosion and degradation than are soil types such as the Oxisols and Vertisols. ICRISAT's

Resource Management Program has historically placed a great deal of emphasis o Vertisol soil and water management. According to Stewart *et al.* (1991) thes soils represent only 6.3% of the land area in the semi-arid tropics of th developing world (Table 8). On the other hand Alfisols, which apparentl represent a much greater challenge to ensure sustainability in the longer term, represent an area some five times larger than that occupied by the Vertisols. Altogether there are four soil types with significantly more land area than Vertisols in the semi-arid tropics.

A question ICRISAT should ask itself is; whether it has the balance right in the emphasis on these various soil types in the context of a natural resource management research agenda for the future?

To quote from Stewart *et al.* (1991): "The most abundant soils in the semi-arid tropics are Alfisols, and these soils are extremely vulnerable to erosion, crusting, compaction, drought, and limited rooting depth. Alfisols contain predominantly low-activity clays and have low plant-available water reserves. Improved management systems for conventional cropping of Alfisols have succeeded in increasing yields of conventional crops, largely due to improved cultivars and use of fertilizers. Effective practices for improving soil and water conservation, however, have not been developed. This is primarily because of the extreme structural instability of these soils. Therefore, a critical research need in the semi-arid tropics continues to be the development of management systems that can sustain the soil resource base. This is indeed a challenge, as discussed previously ....Alfisols are inherently low in soil organic matter, even native vegetation, and once they are tilled, the organic matter becomes critically low."

Preliminary analysis by Kelley and his colleagues suggests that in India there are about 25 million poor residing in Alfisol regions, and 9.4 million in Vertisol regions (Table 9). If we add the estimated numbers of poor in vertic soil areas to the figure for the Vertisols we arrive at a number of 42.9 million poor people. This is far in excess of the numbers of poor in India dependent on the Alfisols. The Inceptisols also represent a significant soil group in India from the aspect of rural poverty. Some 30 million absolutely poor people depend on the Inceptisols.

What these statistics illustrate is that from a poverty perspective there may be some reason to place relatively more emphasis on the vertic soils in India. However, from the point of view of sustainability, both in terms of the extent of the problem and the intensity of the challenge, greater attention might be paid to the Alfisols, especially at the dry end of the spectrum. To what extent this might involve a trade-off of socioeconomic impacts in the shorter term is an open question.

Sustainability issues are as important--perhaps more important--in the intensively managed, high-production zones as they are in the marginal zones. Because high-production environments are perceived to have the greatest potential for meeting the continually growing demand for food through larger increases in productivity, high-production environments may indeed be at <u>greater</u> risk. These questions come to mind: How far can we push these systems without jeopardizing their long-term viability? Are the productivity, stability, and environmental risks greater in trying to reach productivity targets in the higher or lower production zones? Can we estimate *(ex-ante)* the risks associated with expected productivity gains from research aimed at higher and lower production zones?

Coarse Grain Choices in Rainfed Areas, an Example from SADC.

The consistent need to purchase family food supplies constitutes a major drain on each semi-arid farmer household's scarce cash resources.

Paradoxically, most farmers in these drought-prone regions have been historically encouraged simply to expand their production of maize. Agricultural policies designed to increase aggregate grain supplies have prompted the promotion of technologies designed for higher-rainfall zones in to the semi-arid cropping system where they were inapproprate. Investment in the development of technologies more suited to the low-rainfall regions have lagged.

Maize remains the most important food crop for the rest of southern Africa. It is, therefore, not surprising that national agricultural policies were formulated to maximize maize production to offset the possibility of grain imports. However, these well-meaning policies have contributed to high risks of food insecurity, undernutrition, and poverty in the extensive semi-arid areas. Here sorghum and pearl millet, and not maize, are the crops that can benefit the poorest of rural farm households, especially under drought conditions such as the one presently prevailing in southern Africa.

Why did this happen? Most research findings on maize are relevant to the high-rainfall areas of southern Africa and not the less-endowed, semi-arid areas. The market systems extract all the surplus grain from high-rainfall areas instead of redistributing it to regions with food deficits. The subsidies given to farmers to increase maize production also encouraged increased consumption of the crop. In Zambia, maize subsidies rose to levels equal to government tax revenues. In Zimbabwe, despite recent attempts at reduction, maize subsidies account for more than one-half the consumer maize-meal price. These policies benefitted the farmers of high-rainfall areas and the urban consumers, at the expense of the population living in the semi-arid tropics.

Despite historical maize promotion campaigns, sorghum and millet still account for more than one-quarter of the cereal grain area of 6 of the 10 SADC countries. Population growth and the persisting threat of drought have stimulated a continuing growth in area sown to these crops in most of the SADC countries. The only country experiencing a significant decline in sorghum and millet area during the last decade is Tanzania. This is largely attributable to the negative response to the mandated sowing of unsuitable varieties of small grains in response to drought during the mid-1970s.

The failure to develop suitable cropping technologies for semi-arid regions has contributed to the region's heavy dependence on cereal grain imports. During the relatively favorable 1988 to 1990 period, the countries of the SADC region annually imported more than 900 000 t of grain at a cost of more than US $ 21 million per annum. Without the contributions of Zimbabwe, the sole grain exporter in the region, SADC annually imported more than 400 000 t of maize alone at an average annual cost of over US $ 60 million. These aggregrate statistics hide the persisting threat of malnutrition in the semi-arid farming regions--even when national grain stocks are relatively high. Although Zimbabwe has been a consistent maize exporter during the past few decades, internal drought relief programs have become an annual exercise. Farmers in some semi-arid regions have experienced drought or severe mid-season dry spells during 8 of the last 12 years. Widespread failures of rainfall have on average affected parts of Masvingo and Matabeleland in Zimbabwe every other year. In the long run, these farmers may be best off seeking jobs in other parts of the country. But the industrial economy currently offers no immediate propsects of absorbing these people, since unemployment rates in Zimbabwe are roughly estimated at over 30%. New technologies are desperately needed to improve the productivity of semi-arid cropping systems. Without such productivity gains, drought relief will simply continue to drain the public treasury.

The average costs of SADC's cereal imports during the recent favourable rainfall years have been dwarfed by the regional import requirements of the current drought year. In early 1992, SADC estimated a need for over 6 million of coarse grain imports at a cost of over US $ 1.5 billion. Further, the combination of drought and massive food imports have severely disrupted the growth paths of the SADC economies. Governments have been forced to reallocate scarce foreign exchange to purchase and transport grain. Investment capital is being redirected to household consumption. Structural adjustment programs have been threatened by negative economic growth rates, high unemployment, and inflation. Indeed, many farmers have been drawn to equat national economic reform programs with the drought.

At the household level, small-scale farmers throughout the region are being forced to sell off farming assets to purchase food. Though grain is being widely distributed under drought relief programs, logistical problems prevent consistent and timely relief. Most households must use their savings to buy grain. Many of the poorer farmers based in semi-arid areas have been forced to reduce their food intake, often dropping back to one meal or less each day. In Zimbabwe, where the effects of the drought are most severe, cattle prices (the value of the farm household's principal source of savings) have commonly declined by 50%, while grain prices have more than doubled. The migration of family members in search of food and money from urban sources is widespread.

Though the severity of the current drought is extreme, these problems have been persistent. Both the problems of drought and the pattern of government response have been cyclical. Following each significant drought, governments call upon farmers to plant more drought-tolerant crops. Yet they have failed to invest in the development and distribution of technologies necessary for such recommendations to be meaningful. Most farmers have only been offered the choice between improved maize cultivars and the traditional sorghum and millet landraces. When improved sorghum or millet varieties have been available (e.g., Serena in Tanzania) these have been proven unsuited to food consumption (e.g., because of high tannin). In effect, pronouncements of the need to respond to drought have not been backed by the means to do so. The promotion of new maize cultivars in drought-prone regions may actually have worsened the impact of drought.

The investments in building regional sorghum and millet research capacities and in developing new production technologies represent a commitment to find a more viable set of longer-term solutions to the region's poor rainfall. These investments, initiated in 1983, are now beginning to bear fruit. For the first time, many small-scale farmers living in semi-arid regions are being offered realistic opportunities to improve their productivity and food supplies. Improved seed, generated with the assistance of ICRISAT, is being distributed in Malawi, Mozambique, Namibia, Zambia, and Zimbabwe. SMIP has directly contributed cultivars for release and also facilitated the movement of advanced materials from ICRISAT's main program in India to southern Africa.

During the USAID-sponsored mid-term evaluation of the regional program in 1991, a conservative estimate was offered that 20% of the total area of sorghum and millet would be sown to improved cultivars by the year 2010. This was estimated to offer an average productivity gain of 20%. Employing a common form of adoption function, this would require at least 100% area coverage by the year 2000. Such technology adoption patterns will yield an overall 37% annual rate of return on the full set of national and regional investment costs in sorghum and millet research.

This evaluation goes on to indicate: "*The overall returns to investment in research in small grains have the potential to match those from most agricultural research investments. Many studies have suggested that returns to investment in agricultural research commonly range between 30 and 50%. Use of conservative assumptions offers considerable confidence of a positive outcome on the long-term investment in research on sorghum and millet.*"

Additional measures are needed to account for the impact of expected productivity gains on the lives and welfare of small-scale farmers. Rough calculations indicate the anticipated yield gains can increase the average family's food supplies by the equivalent of 1.5 months of grain. This can offset the need to allocate scarce cash to food purchases in years of favourable rains. Rather than being consumed, such monies can be invested in mesures to improve household productivity--school fees, new production technologies and livestock. Livestock offer both a means to generate income (by providing plowing services, transport, meat, and milk) and as a means of family savings (a capital store that can be quickly liquidted when cash is needed). The direct income gains will be multiplied in the rural economy. During years of drought, the yield gains will offer an essential means to reduce malnutrition. Losses associated with family dislocation and poor health, welfare declines with lasting effects, may be avoided.

Such gains to the welfare of low-income households and communities compare favorably with the projected gains in aggregate national income. These are advantages that cannot simply be measured in economic rates of return or in the increments to average household income. Households based in the extensive semi-arid regions of southern Africa are being given the opportunity to contribute to the production of national wealth, and not simply to gain from its redistribution.

ICRISAT's FUTURE PLANS

We have just completed the preparation of our Medium Term Plan for the period 1994-98 for submission to TAC and the CGIAR.

The features of our Plan are that it:

- is analytically rigorous;
- is transparent in the process and criteria used to make the choices;
- draws on an extensive agroclimatic and socioeconomic database built up by ICRISAT Center;
- involved all scientists in the Institute and the major NARSs in an interactive and iterative process of elicitation of their objective knowledge and subjective scientific intuition about the various biotic, abiotic, and socio-economic constraints to agricultural production in the semi-arid tropics, and the prospects that research by ICRISAT and NARSs can help alleviate them.

Based on a detailed analysis of the economic consequences of the various constraints operating on the mandate crops and the semi-arid tropical environment a total of 132 potential research themes were identified. These themes were ranked using four criteria:

a) Efficiency as measured by the net benefit/cost ratio, which is estimated from the economic value of success in the conduct of the research, the likelihood of success, the potential for spillovers of an economic, scientific, or an agroecological character, research and adoption lags, and the influence of markets;

b) Equity as measured by two variables--the number of absolutely poor people in the research domains where the constraints were judged to be serious, and the number of female illiterates in the same domains;

c) Internationally as measured by the Simpson Index of Diversity; and

d) Sustainability as measured by the likely contribution of research on the theme to the conservation of the natural resource base.

Each of these four criteria were given an equal weight and an additive weighted average composite index was calculated, after normalizing the variables used in their construction. All 132 research themes were then arranged in priority sequence according to the composite index, and the cumulative annual cost calculated to enable the cut-off points to be determined based upon the resource envelopes specified by the Technical Advisory Committee (TAC).

In developing the protocols for the 132 potential research themes, considerable attention was given to the delineation of the appropriate research domains where the various constraints expressed themselves. We defined research domains as somewhat homogeneous ecoregions where the relevance of strategic research is expected to be pervasive throughout the geographical areas of which they are comprised. They were defined in such a way that we could relate the potential impact of research themes to the defined primary and secondary domains, the latter benefitting from spillover effects.

The crop improvement programs used production systems and yield constraints as the primary criteria for defining their domains, or zones of adaptability. The Resource Management Program found that soil and climate-based research domains were the most appropriate way to view research opportunities.

The results of the analytical process, which proved to be a stimulating professional experience for ICRISAT's scientific staff, led to a clear set of core and complementary research themes.

As a result we have proposed to TAC that, using the criteria we established for setting priorities, 92 themes deserve to be included in the core program and 18 are suitable for complementary funding. 22 themes were excluded from the proposed portfolio on the basis that ICRISAT does not have a comparative advantage in addressing them.

The total cost for the 92 research themes is $US 30.18 million per annum in today's dollars. This is almost 10% above the projected mean resource envelope suggested by TAC. These 92 research themes and the associated cost of $US 30.18 million are referred to as Plan A in the Medium Term Plan.

Contrary to TAC's recommendation in Priorities and Strategies paper, that ICRISAT crop improvement work on pigeonpea should be phased out our analysis shows that the Plan A research portfolio in the next medium term plan should include pigeonpea improvement at about the same level as in 1992. Recall that the 11 pigeonpea research themes were subjected to the same scrutiny and methodology as all the other 121 themes considered.

Appendix 3 contains a detailed analysis of the 110 core and complementary research themes which are ranked in order of priority based on a composite index of the above four criteria.

An analysis of the 92 research themes included in Plan A shows that 80% of them can be classified as relating directly to the priorities determined in Agenda 21 of UNCED (Figure 4). We therefore firmly believe that our portfolio, besides being clearly focussed on the mandate of the CGIAR, also addresses the contemporary concerns of the international community about the environment and sustainability.

Some of the remaining challenges we face which are included in the 110 research themes we have identified are as follows.

Sorghum

Striga is a parasitic weed that reduces yield in sorghum in Asia and Africa. The global losses in sorghum production caused by *Striga* are estimated at US $ 764 million per annum, and continental loss at US $ 89 million per annum in Africa. We have made only a limited progress in eradicating this weed. ICRISAT scientists in western Africa were able to control *S. hermonthica* in a heavily infested farmer's field through soil solarization. Fields kept moist for 2-3 weeks in the off-season, when soil temperature during the day is above 45°C, greatly reduced the large reservoir of *Striga* seeds stored in the upper 100 mm of infested soils. Solarization could be a useful research station tool, but is too expensive to be considered a practical control technique for farmers. Two ICRISAT *Striga*-resistant varieties, SRN 39 and IS 9830, were released for cultivation in *S. hermonthica* endemic areas in Sudan in 1991. Our efforts will continue to improve resistance to *Striga* in sorghum using conventional and new technologies.

Pearl millet

The success of pearl millet in the harsh environments of the arid and semi-arid tropics relates largely to its ability to thrive under high temperatures when water is available, and to tolerate them when it is not. Efforts to improve pearl millet in India through crop breeding have focused on F_1 hybrids and open-pollinated medium-duration varieties, with emphasis on heat and drought tolerance. Increasing productivity through improved cultivars and management practices in the driest areas remains a challenge, but new cultivars with much shorter duration appear to offer many advantages. ICRISAT pearl millet breeders and economists tested a range of cultivars in farmer-managed trials in several villages in the state of Rajasthan in India and ascertained farmers' preferences for different varietal characteristics. The findings have been incorporated into the choice of cultivars for future tests. The objective of the program is to combine the adaptive traits of traditional landraces with the yield potential of improved varieties.

Chickpea

A high level of resistance to ascochyta blight does not exist in currently used cultivars, especially in Pakistan and northern India where the disease can devastate the entire crop. Work by our chickpea breeder located at ICARDA, Syria has led to the availability of cultivars with an acceptable level of resistance in the West Asia/North Africa (WANA) region; but these have not been successful in the Indian subcontinent. Germplasm enhancement is important for ascochyta blight resistance. Chickpea plants are being screened under a severe selection pressure at ICRISAT Center, Patancheru in a large growth room, where the temperature is maintained at 20±1°C and the relative humidity is kept close to 100%. Our efforts are also directed to transfer genes for resistance to ascochyta blight from wild *Cicer* species to cultivated chickpea through wide hybridization and embryo rescue.

Low temperature (below 5°C) during the reproductive phase of the crop is the major abiotic constraint in chickpea-growing areas of northern India and the WANA region. Through field evaluation trials at Hisar and Gwalior in India, we identified genotypes tolerant to low temperature. By further breeding and selection we will develop plant types that can produce pods at low temperature. Cultivars with moderate levels of resistance to cold were developed by our breeding program at ICARDA, Syria and released in the WANA region. However, the objective of the program is to develop improved varieties with high levels of resistance to cold through conventional breeding and interspecific hybridization.

Pigeonpea

Pod borer (*Helicoverpa armigera*) is the major and most damaging insect pest of pigeonpea, especially in India. ICRISAT's integrated pest management (IPM) program aims at optimizing crop management procedures to control this pest and to promote sustainable agricultural systems. The primary thrust of our IPM research is host-plant resistance. Although we have developed pigeonpea genotypes that are less susceptible to the pod borer, than others, the level of resistance in these sources is low. Efforts are in progress to increase the gene frequency in populations that have pod borer resistance. Also, most of the *Helicoverpa*-resistant selections are susceptible to fusarium wilt, a major disease and yield reducer of pigeonpea. Hence, we are also evaluating progenies for combined resistance to *Helicoverpa* and wilt.

Sterility mosaic is an important disease of pigeonpea in Asia. In 1991, the disease was estimated to cause an annual loss of about US$ 280 million in India alone. We have developed several lines resistant or moderately resistant to the disease and a few have been released in India and Nepal. Although the symptoms and mode of transmission of the disease would implicate a virus, our efforts during several years of research in identifying the casual agent have been unsuccessful. In recent attempts, we used molecular biological techniques and isolated one dsRNA that was consistently found in infected material. Efforts to clone and construct a genomic map are continuing.

Groundnut

Leaf spots (early and late) are the most important foliar diseases of groundnut causing severe yield losses in Asia, Africa, and America. We have developed high-yielding varieties with moderate levels of resistance to leaf spots. ICGS MS 42, a high-yielding cultivar, is less susceptible to early leaf spot and has been released in Malawi and Zambia. We are using both conventional and biotechnology techniques to incorporate genes for resistance to leaf spots from wild *Arachis* to cultivated species and develop improved varieties. Interspecific hybrid derivatives with resistance to leaf spots have been developed. These derivatives will be used to enhance the levels of resistance to early and late leaf spots in released cultivars.

Conservation and production

Since water and soil fertility are the two major constraints to increased and stabilized agricultural production in the rainfed-farming areas, every effort must be made to conserve both water and soil resources. Rainwater management and the implementation of soil conservation programs hold the key to an ecologically balanced improvement in the quality of rainfed lands.

Amongst the major rainfed semi-arid tropical countries, India has done exceedingly well in giving priority to rainfed land development programs. Many watersheds (approximately 5000 ha each in size) have been delineated across the country. The ICAR has provided expertise in tackling agricultural production and related soil and water conservation problems in 37 'model watersheds'. Scientists are working with policy-makers, extension workers, and farmers.

Progress has, however, been slow. Development of watersheds requires grid surveys, land leveling, land shaping, and an integrated drain network. Many different agencies have to pool their expertise and databases. Further, it must be made clear to the farmers participating in the watershed program that they stand to gain from differential benefits as individuals. For example, those farmers whose lands are located in the upper reaches of the watershed may gain less because water from their lands drains off easily (although they lose more soil through soil erosion). On the other hand, farmers whose lands are located in the lower reaches of the watershed, and where crops suffer from water stagnation more often, stand to gain from improved drainage brought about by watershed development. Thus, the development costs of the on-farm watershed program vary considerably among beneficiaries leading to difficulty in apportioning costs among participating farmers. For a watershed program to be successful the land in a watershed must be managed to conserve soil and water. Often it is difficult for participating farmers to agree on a single approach.

Where watersheds have been developed with full subsidy, spectacular increased crop yields and soil/water conservation have been achieved. But the framework of a watershed is soon dismantled by the farmers when the government/agency withdraws supervisory or financial support. One of the major challenges of the coming decade will center around human resource development so that farmers are motivated to produce and protect resources. Resolution of conflicts and speedy removal of obstacles to implement watershed technology would be required. New approaches in extension education and a renewed thrust in creating awareness and in participatory methods are needed. We are cooperating with the Central Institute for Dryland Agriculture in monitoring the performance of some model watersheds laid across diverse agroecological zones across India.

Implementing land-use policy

Semi-arid rainfed countries have diverse soil and agroclimatic resources. The production potential for different eco-regions is widely different. Without the wise and sustainable use of soil and water resources, the development of rainfed farming areas is not possible. The optimal use of land requires that land resources be well characterized and their spatial relations be delineated by using GIS techniques, and their capacities for all likely uses, at various levels of management, be determined and implemented.

Many crops are grown in rainfed areas, cereals being the most dominant. Since irrigated lands are most suitable for the production of cereals, every effort should be made to grow more pulses, oilseeds, and other cash crops so as to diversify agriculture in the rainfed lands. Legume crops must have an important place in crop rotations so that minimal nitrogenous fertilizer inputs are needed. In future, chemical fertilizers will be used extensively for economic reasons, on prime lands with least risk of crop failure. In India already a noticeable increase in the acreage devoted to pigeonpea and groundnut crops in the rainfed areas has been registered. The area under sorghum and pearl millet is on the decline. This trend should be maintained.

Shifts in land-use policies, particularly in the rainfed farming areas, will have to be supported by the provision of appropriate land tenure, effective demonstration of wise and profitable uses of land, guidance and interventions by research and extension institutions, and the incentives provided by market forces. The most important factor is commitment of the people who use and occupy the land. There is no sustainable agriculture without stewardship. ICRISAT has successfully used GIS technology at ICRISAT Center for ISC. We are working in close concert with UNEP/GRID, FAO and NARSs in analysing land resources data bases to define appropriate land uses.

Eco-interdependency of rainfed and irrigated areas

The idea of hierarchical and interlinked systems in ecology has been accepted by scientists. Eventually all agricultural ecosystems interact through transfer of soil, water, and nutrient resources. With increasing use of chemical fertilizers and pesticides, the global change of rainfed and irrigated land-use systems has become intractably interdependent. Ecological protection of rainfed farming areas is necessary if continued rich harvests are to be expected from irrigated lands. Eroding rainfed areas can silt reservoirs, choke canals and waterways, and thus lead to irrigation inefficiency. Similarly, large-scale use of nitrogenous fertilizers in irrigated areas, could lead to pollution of limited water resources of rainfed farming regions. The global environmental security of irrigated and rainfed areas is thus closely linked. Some mechanism of transferring resources to ecologically maintain rainfed farming must be underwritten by high output irrigated agriculture areas.

Increasing crop productivity in the endowed environments, both in the irrigated and rainfed areas, should be a high priority. The technologies to reduce risks to dependable crop production in the medium rainfall (750-1200 mm) zone for which improved rainfed farming methods are available will have to be speedily implemented. Rainfed agriculture is the only source of land for meeting future needs of industry and forestry. All marginal and ecologically fragile lands must be mapped and progressively used for needs other than annual crop cultivation. In India we are currently working on a program to map soil degradation in the dryland semi-arid tropics in cooperation with the National Bureau of Soil Survey and Land use Planning. This work will be extended to the African SAT over the next few years.

Providing increased employment

Currently migration of labor (particularly able-bodied persons) from rainfed farming to urban areas is substantial. A higher rate of productive employment through improved technology is one of the most desirable social equity goals in the coming decade, to achieve overall growth of employment opportunities in rainfed farming areas. Poverty and underemployment are positively related (Dantwala, 1979) and more employment would therefore benefit the poor. Our research has shown that farm labor employment is substantially higher when watershed-based improved rainfed technologies generated by ICRISAT in cooperation with the Indian NARS are utilized (von Oppen *et al.*, 1989). The number of labor-days required in the implementation of improved technologies is more than twice the need of traditional systems. Moreover, watershed-based technology is likely to provide more stable employment than the existing technology, while stability in employment would help reduce the seasonal underemployment (and emigration) prevalent in rainfed areas.

Upgrading infrastructure

A key element in the success of any agricultural development program is the availability of rural infrastructural facilities. This implies that good quality seeds, tree nurseries, appropriate chemical fertilizers, plant protection material, and credit/marketing facilities are equitably and readily available. Currently, there is a large gap between the requirement of infrastructure facilities and their present status in rainfed lands. Among the various options that may be available, one that has worked well in several rainfed farming regions is the creation of a network of 'farmer organized and operated cooperatives'. This gives the farmers a joint leverage to purchase inputs at competitive rates in bulk. It also assures the quality and timely availability of inputs and the arrangement of bulk credit. We are working with the sand industry, agricultural banking systems and others to highlight the special requirements for infrastructure in rainfed agriculture.

CONCLUSION

It is our belief that the best is yet to come from ICRISAT in terms of scientific accomplishments and socioeconomic impacts. Twenty years of research on crops and environments neglected for so long has provided the necessary foundation on which to build future achievements.

An example is the identification, for the first time in non-west African material, of resistance to groundnut rosette virus, one of the most pervasive viruses affecting the groundnut crop in Africa. Overcoming groundnut rosette virus disease was a dream when our Groundnut Program began in 1976. It took considerable cytogenetic and cell biology input to arrive at this position. ICRISAT was ahead of its time in recognizing the need to incorporate biotechnology to overcome this biotic constraint. The real dividends hopefully are about to be realized.

A second example is the release of the world's first pigeonpea hybrid. This has created considerable excitement in both the private and public seed sectors in India. The challenge is to capitalize on this unique achievement by enhancing resistance to pests in the new hybrids and to develop cytoplasmic male sterility to make hybrid seed production more cost-effective. We have opened exciting new opportunities; we require further research to effectively capitalize on them.

It is pleasing to note that the suite of downy mildew resistant improved pearl millet cultivars commencing with ICMV 1 (WC-C75) which ICRISAT developed with its ICAR collaborators, is currently generating new income streams for the poor in India far in excess of the current annual core budget of the whole Institute. This is but one of the many technology options the Center has been instrumental in developing in the past 20 years. We are confident with the initiation of more systematic economic assessments of the impact of our collaborative research with NARS commencing in 1992,
we will be able to document even more convincing evidence of the wisdom of donor support for ICRISAT.

Our 1991 report clearly illustrates the increasingly strategic focus of

ICRISAT's research portfolio. This has been a purposive strategy in recognition of the growing strength of many of our NARS partners, especially in Asia. Examples include the work on the role of central leaf whorl wetness in shoot fly susceptibility in sorghum, and the discovery of a new geminivirus of chickpea transmitted by leafhoppers. As we move away from the development of finished cultivars in countries such as India, the scope and value of strategic efforts such as these will increase. We recognize, as should donors, that as our strategic research agenda grows, it becomes more challenging to be able to assess the precise impact of ICRISAT's research. We are of the view that for this reason, and the increasingly collaborative nature of our relationships with NARS, assessments of socio-economic impacts should not aim at separate attributions to NARS and ICRISAT, but rather at the joint impacts.

The challenge for national and international agricultural research transcends the "food first" imperatives of the sixties and seventies. In the nineties and beyond, the objectives are threefold; increased agricultural productivity, poverty alleviation, and sustainable agricultural development.

Agenda 21, which emerged from the recent UNCED conference in Rio de Janeiro, closely parallels ICRISAT's agenda. It points out that the issues of sustainability and resource conservation are more complex than merely increasing the productivity of individual crops. To expand our research on natural resource management, ICRISAT needs greater interaction with our partners in the national programs and a longer time horizon to achieve meaningful results.

The rainfed semi-arid tropics, where the poor live close to the margin of existence, where the environment is fragile from excessive population pressure, and where irrigated agriculture is reaching the limits of viability, is a very difficult region. Yet these areas will need to provide livelihoods for the bulk of the rural poor for decades.

The complexity of the new challenges thus requires greater resources for research, not less, as has been the trend in recent years. The rainfed lands of the developing world deserve a greater commitment in the agricultural strategies of governments, aid agencies, and the scientific community.

In sum, let me say that while ICRISAT's challenges are great, our commitment to the people of the semi-arid tropics is clear.

Table 1. Cereal demand growth to 2030.

Crop	Increase per year (%)
All	2.3
Coarse grains	3.2
Wheat	2.3
Rice	1.3

Source: Crosson and Anderson, 1992.

Table 2. Growth of irrigated land in less-developed countries.

Period	Increase per year (%)
1950-60	4.5
1961-70	3.5
1971-85	2.1
Since 1985	Less than 1.0

Source: Stewart *et al.*, 1991.

Table 3. Probablities of growing season length exceeding specified durations for variable onset of rains for Niamey, Niger[1].

Date of onset of rains	Probability(%) of length of growing season exceeding specified duration (days)			
	80 days	100 days	120 days	140 days
24 May	100	98	71	15
02 June	100	91	40	3
12 June	98	71	15	0
22 June	91	40	3	0
02 July	71	15	0	0

1. Based on data from 1904-84 (Sivakumar, 1990).

Table 4. Grain yields under improved and traditional technologies on deep Vertisols[2] at ICRISAT Center[3] in 13 successive years[1].

	Grain yield (t/ha)					
	Improved system (double cropping)				Traditional system (single crop)	
Year	Cropping period rainfall (mm)	Sorghum/ Maize	Sequential chickpea or intercropped pigeonpea	Total	Sorghum	Chickpea
1976/77	708	3.20	0.72	3.92	0.44	0.54
1977/78	616	3.08	1.22	4.30	0.38	0.87
1978/79	1089	2.15	1.26	3.41	0.56	0.53
1979/80	715	2.30	1.20	3.50	0.50	0.45
1980/81	715	3.59	0.92	4.51	0.60	0.56
1981/82	1073	3.19	1.05	4.24	0.64	1.05
1982/83	667	3.27	1.10	4.37	0.63	1.24
1983/84	1045	3.05	1.77	4.82	0.84	0.48
1984/85	546	3.36	1.01	4.37	0.69	1.23
1985/86	477	2.70	0.73	3.43	-[4]	0.84
1986/87	585	4.45	0.38	4.83	0.37	1.27
1987/88	841	4.26	1.35	5.61	0.80	0.92
1988/89	907	4.64	1.23	5.87	0.61	1.18
Mean	771	3.33	1.07	4.40	0.59	0.86
SD	205	0.76	0.34	0.76	0.15	0.32
CV (%)	27	23	32	17	25	37

1. Source: Sivakumar, et. al., 1992.

2. Available water-holding capacity is 150 cm /m of soil depth.

3. Average rainfall for Hyderabad (29 km from ICRISAT Center) based on 1901-84 data is 784 mm with a CV of 27%.

4. - = No crop sown.

Table 5. Grain yields of some cropping systems on vertic soils[1] under low and medium fertility at ICRISAT Center in operational scale experiments[2].

Year	Cropping period rainfall (mm)	Soil fertility	Sole Pigeonpea	Sorghum/ Pigeonpea	Millet/ Pigeonpea	Groundnut/ Pigeonpea	Sole sorghum
1981/82	1073	Low[3]	700	937	1201	1387	516
		Medium[4]	868		2175	3681	3234
1982/83	667	Low	1041	2219	2190	2214	1170
		Medium[5]	1217	4291	3178	2917	2869

1. Available water-holding capacity of 50 cm soil profile is 80 mm.

2. Source: ICRISAT (1983, 1984).

3. Low = 0-0-0 NPK.

4. Medium = 60-13-0 NPK in sole sorghum and cereal/legume intercrop systems; 30-13-0 NPK in sole pigeonpea and groundnut/pigeonpea.

5. Medium = 60-13-0 NPK in sole sorghum and cereal/legume intercrop systems; 0-0-0 NPK in sole pigeonpea and groundnut/pigeonpea.

Table 6. Annual water balance (mm) and soil loss (t/ha) for traditional and improved technologies in Vertisol watersheds, ICRISAT Center, 1976/77 to 1983/84[1].

Farming systems technology	Water-balance (mm)				
	Annual rainfall	Water used by crops	Water lost as surface runoff	Water lost as bare soil evaporation and deep percolation	Soil loss (t/ha)
<u>Improved system</u>					
Double cropping on broadbed and furrows improved crop and fertility management	904	602(67)[2]	130(14)	172(19)	1.5
<u>Traditional system</u>					
Single crop in postrainy season and cultivation on flat with traditional crop and fertility management	904	271(30)	227(25)	406(45)	6.4

1. Source: Sivakumar *et al.*, 1992.

2. Figures in parentheses are amounts of water used or lost expressed as percentage of total rainfall.

Table 7. Poverty and production in SAT India.

SAT region	Numbers of absolutely poor (million)	Annual gross value of production 1985-87 (US$ million)		
		ICRISAT crops	Other crops	Total
Less-assured	50	3,943	6,122	10,065
More-assured	51	2,398	8,642	11,040

Source: Kelley *et al.*, ICRISAT, personal communication, 1992.

Table 8. Land area of soil orders in SAT.

Soil order	Land area (%)
Alfisols	33.0
Aridisols	24.8
Entisols	13.0
Oxisols	9.0
Vertisols	6.3
Mollisols	3.7
Inceptisols	3.2
Ultisols	2.5

Source: Stewart *et al.* 1991.

Table 9. Absolute poverty in India's SAT.

Soil type	Number of poor (millions)
Vertics	33.5
Inceptisols	29.9
Alfisols	25.1
Vertisols	9.4

Source: Kelley *et al.* ICRISAT, personal communication, 1992.

Appendix Table 1.

Cumulative list of releases of ICRISAT plant material and NARS plant material using ICRISAT germplasm, up to December 1991.

ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
Sorghum			
Sel. from crosses from Chapingo		Centa S-2	Released cultivar in El Salvador (1976)
Sel. from crosses from E. Africa		Valles Altos 110	Released cultivar in Mexico (1978)
ATx623 x Sweet Sudan		Centa SS-41 (forage)	Released cultivar in El Salvador (1980)
A 6072		Yuan 1-54	Released cultivar in China (1982)
A 3681		Yuan 1-98	Released cultivar in China (1982)
A 3872		Yuan 1-28	Released cultivar in China (1982)
A 3895		Yuan 1-505	Released cultivar in China (1982)
Hageen Durra 1		Hageen Durra 1	Released hybrid in Sudan (1982) Male sterile parent, ATx623 from Texas A&M University. Pollinator, Karper 1597 from ICRISAT.
Sel. from M 91057		ISIAP Dorado Blanco 86	Released cultivar in El Salvador (1983) Released cultivar in Mexico (1986)
Sel. from CS 3541		Tortillero 1	Released cultivar in Honduras (1984)
ATx623 x Tortillero 1		Catracho	Released cultivar in Honduras (1984)
ICSV 2	SPV 386	ZSV 1	Released cultivar in Zambia (1983)
IS 9302	IS 9302	ESIP 11	Released cultivar in Ethiopia (1984)
IS 9323	IS 9323	ESIP 12	Released cultivar in Ethiopia (1984)
ICSV 1	SPV 351	CSV 11 SPV 351	Released cultivar in India (1984) Released cultivar in Malawi (1989)
M 90906	Schwe phyu 1	Yezin 1	Released cultivar in Myanmar (1984)
M 36248	Schwe phyu 2	Yezin 2	Released cultivar in Myanmar (1984)
M 36335	Schwe phyu 3	Yezin 3	Released cultivar in Myanmar (1984)
M 36172	Schwe phyu 4	Yezin 4	Released cultivar in Myanmar (1984)
ICSV 112	SPV 475	SV 1 UANL-I-187 CSV 13 Pacifico 301 Pinolero I	Released cultivar in Zimbabwe (1987) Released cultivar in Neuvo Leon, Mexico (1987) Released cultivar in India (1988) Released cultivar in Mexico (1990) Released cultivar in Nicaragua (1990)
M 62650		Sureño	Released cultivar in Honduras (1985)
SEPON 77		Nica-sor (T 43)	Released cultivar in Nicaragua (1985)
M 90975	ICTA C-21	ICTA Mitlan 85	Released cultivar in Guatemala (1985)
ICSH 153	SPH 221	CSH 11	Released hybrid in India (1986) Male-sterile parent 296A from AICSIP. Pollinator MR 750 from ICRISAT.
M 90362		UANL-I-287	Released cultivar in Neuvo Leon, Mexico (1987)
AGROCONSA I		AGROCONSA I	Released hybrid in El Salvador (1987) Male sterile parent ATx625 from Texas A&M University. Pollinator M 90362 from ICRISAT.

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ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
ICSV 88060		SV 2	Released cultivar in Zimbabwe (1987)
ICSV 145	SPV 694	SAR 1	Resistant to *Striga asiatica* in India. Recommended for cultivation in *Striga*-endemic areas of India, except Karnataka state (1988)
Liao Hybrid no. 4		Liao Hybrid no. 4	Released hybrid in China (1988). Male sterile parent SPL 132A from ICRISAT. Pollinator from China.
M 62641		Costeño 201	Released cultivar in Mexico (1989)
SDS 3220		Macia	Released cultivar in Mozambique (1989)
IS 8571		Mamonhe	Released cultivar in Mozambique (1989)
WSV 387		Kuyuma	Released cultivar in Zambia (1989)
WSV 187		Sima	Released cultivar in Zambia (1989)
IS 2391		SDS 1513	Released cultivar in Swaziland (1989)
IS 3693		SDS 1594-1	Released cultivar in Swaziland (1989)
E 1966	IS 30468	NTJ 2	Pure line selection from a germplasm line released in Andhra Pradesh, India for postrainy season cultivation (1990)
ICSV 1007 HV	SRN 39	Mugawim Buda 1	Released in Sudan for *Striga hermonthica* endemic rainfed, mechanized farming areas. It has a broad-spectrum resistance throughout the *Striga*-infested areas of the world (1991)
IS 9830		Mugawim Buda 2	Released in Sudan for *Striga hermonthica* endemic rainfed farming conditions (1991)
M 91057	ICTA C-25	Istmeño	Released cultivar in Mexico (1991)
PP 290		Perlita	Released cultivar in Mexico (1991)
Sel. from M 90362		Escameka	Released cultivar in Costa Rica (1991)
Sel. from ISIAP Dorado		Alanje Blanquito	Released cultivar in Panama (1991)
Pearl Millet			
Serere Composite 2		Ugandi	Released in Sudan (1981) Developed at Serere station, Uganda; introduced into Sudan by ICRISAT
ICMV 1	WC-C75	WC-C75	Released cultivar in India (1982) Released cultivar in Zambia (1987)
ICMV 4	MP 15	ICMS 7703	Released cultivar in India (1985)
ICMV 5	ITMV 8001	ITMV 8001	Released cultivar in Niger (1985)
ICMV 6	ITMV 8002	ITMV 8002	Released cultivar in Niger (1985)
ICMV 7	ITMV 8304	ITMV 8304	Released cultivar in Niger (1985)
ICMH 451	MH 179 (ICH 451)	ICMH 451 (MH 179)	Released hybrid in India (1986)
ICMH 501	MH 180 (ICH 501)	ICMH 501 (MH 180)	Released hybrid in India (1986)
ICMH 423	MH 143 (ICH 423)	ICMH 423	Released hybrid in India (1986)
ICMA 1 ICMB 1	81A 81B		Released seed parent of hybrid ICMH 451 in India (1986)
ICMA 4 ICMB 4	834 A 834 B		Released seed parent of hybrid ICMH 501 in India (1986)
ICTP 8203	ICTP 8203	MP 124 Okashana 1 PCB 138	Released cultivar in Maharashtra and Andhra Pradesh states, India (1988) Released cultivar in Namibia (1989) Released cultivar in Punjab state, India (1989)

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ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
ICMA 2 ICMB 2	843 A 843 B		Released seed parent of hybrid HHB 67 in India (1989)
ICMB 841	ICMB 841	ICMB 841	Released seed parent of hybrids Pusa 23 and ICMH 423 in India (1988)
ICMA 841	ICMA 841	ICMA 841	Released seed parent of hybrids Pusa 23 and ICMH 423 in India (1988)
ICMV 82132		Kaufela	Released cultivar in Zambia (1989)
		IKMV 8201	Released cultivar in Burkina Faso (1991)
ICMV 155	ICMV 84400, MP 155	ICMV 155	Released cultivar in India (1991)
Late Backup Composite		Lubasi	Released cultivar in Zambia (1991)

Finger Millet

ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
IE 2929		Lima	Released cultivar in Zambia (1989)

Chickpea

ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
ICC 8521		Aztec	Released cultivar in USA (mid 1980s)
ICCV 1	ICCC 4	ICCC 4	Released cultivar in Gujarat state, India (1983)
		Sita	Released cultivar in Nepal (1987)
Sel. from ICC 12366	JG 62 × F 496	RSG 44	Released cultivar in India (1984)
Sel. from ICC 14302	F 378 × F 404	Anupam	Released cultivar in India (1984)
Sel. from L 550 × L 2		GNG 149	Released cultivar in India (1985)
ILC 72 (ICARDA)		Fardan	Released cultivar in Spain (1985)
		Califfo	Released cultivar in Italy (1987)
ILC 200 (ICARDA)		Zegri	Released cultivar in Spain (1985)
		Atalaya	Released cultivar in Spain (1985)
ILC 2548 (ICARDA)		Almena	Released cultivar in Spain (1985)
ILC 2555 (ICARDA)		Alcazaba	Released cultivar in Spain (1985)
FLIP 83-46C (ICARDA)		Kassab	Released cultivar in Tunisia (1986)
Be-sel-81-48 (ICARDA)		Amdoun 1	Released cultivar in Tunisia (1986)
ILC 195 (ICARDA)	ILC 195	ILC 195	Released cultivar in Turkey (1986)
		ILC 195	Released cultivar in Morocco (1987)
ILC 482 (ICARDA)	ILC 482	Guney Sarisi 482	Released cultivar in Turkey (1986)
		Ghab 1	Released cultivar in Syria (1986)
		ILC 482	Released cultivar in Morocco (1987)
		ILC 482	Released cultivar in Algeria (1988)
		TS 1009	Released cultivar in France (1988)
		Janta 2	Released cultivar in Lebanon (1989)
		Jubeiha 2	Released cultivar in Jordan (1990)
		ILC 482	Released cultivar in Iran (1991)
ILC 3279 (ICARDA)	ILC 3279	Yialousa	Released cultivar in Cyprus (1984)
		Chetoui	Released cultivar in Tunisia (1986)
		Ghab 2	Released cultivar in Syria (1986)
		Sultano	Released cultivar in Italy (1987)
		ILC 3279	Released cultivar in Algeria (1988)
		Jubeiha 3	Released cultivar in Jordan (1990)
		ILC 3279	Released cultivar in Iran (1991)
ICCL 83110		ICCL 83110	Released cultivar in Kenya (1986)
Sel. from K 850 × F 378		Schwe K[illegible]mon	Released cultivar in Myanmar (1986)
ICC 552	P 436	Yezin 1	Released cultivar in Myanmar (1986)

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ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
ICCL 81248		Nabin	Released cultivar in Bangladesh (1987)
ILC 464 (ICARDA)	ILC 464	Kyrenia	Released cultivar in Cyprus (1987)
ILC 1335 (ICARDA)		Shendi	Released cultivar in Sudan (1987)
ICC 6098	JG 74	Radha	Released cultivar in Nepal (1988)
Sel. from 850-3/27 × F 378		Mariye	Released cultivar in Ethiopia (1988)
ILC 202 (ICARDA)		ILC 202	Released cultivar in China (1988)
ILC 411 (ICARDA)		ILC 411	Released cultivar in China (1988)
FLIP 81-293C (ICARDA)		TS 1502	Released cultivar in France (1988)
ILC 237 (ICARDA)		ILC 237	Released cultivar in Oman (1988)
ICCV 2	ICCL 82001	Swetha	Released in Indian states of Andhra Pradesh, (1989), Maharashtra (1991)
ICCC 37	ICCL 80074	Kranthi	Released cultivar in Andhra Pradesh state, India (1989)
ILC 5566 (ICARDA)		Elmo	Released cultivar in Portugal (1989)
FLIP 85-17C (ICARDA)		Elvar	Released cultivar in Portugal (1989)
ICCV 6	ICCC 32	Kosheli	Released cultivar in Nepal (1990)
ICCL 82108		Kalika	Released cultivar in Nepal (1990)
FLIP 85-7C (ICARDA)		Damla 89	Released cultivar in Turkey (1990)
FLIP 85-135C (ICARDA)		Tasova 89	Released cultivar in Turkey (1990)
FLIP 84-79C (ICARDA)	FLIP 84-79C	FLIP 84-79C FLIP 84-79C	Released cultivar in Algeria (1991) Released cultivar in Tunisia (1991)
FLIP 84-92C (ICARDA)	FLIP 84-92C	FLIP 84-92C FLIP 84-92C FLIP 84-92C	Released cultivar in Algeria (1991) Released cultivar in Morocco (1991) Released cultivar in Tunisia (1991)
FLIP 82-150C (ICARDA)		Ghab 3	Released cultivar in Syria (1991)
87AK71115		Akcin	Released cultivar in Turkey (1991)
Pigeonpea			
Prabhat × Baigani	QPL 1 Hunt	Hunt Megha	Released cultivar in Australia (1983) Released cultivar in Indonesia (1987)
ICPV 1	ICP 8863	Maruti	Released cultivar in Karnataka state, India (1985)
T 21 × A 277	QPL 42	Quantum	Released cultivar in Australia (1985)
ICP 7035		Kamica	Released cultivar in Fiji (1985)
ICPL 87		Pragati ICPL 87	Released cultivar in India (1986) Released cultivar in Myanmar (1990)
ICP 9145	ICP 9145	Nandolo Wansawara	Released cultivar in Malawi (1988)
Sel. from (Prabhat × HY 3C) × (ICP 7018 × ICP 7035)		Quest	Released cultivar in Australia (1988)
ICPL 151		agriti	Released cultivar in India (1989)
ICPL 332		Abhaya	Released cultivar in India (1989)
ICPH 8		ICPH 8	Released hybrid in India (1991)
Groundnut			
Sel. from ICGS 1		Spring Groundnut '84 Konkan Gaurav	Released cultivar in Punjab state, India for spring cultivation (1984) Released cultivar in Maharashtra state, India (1991)
JL 24		Sinpadetha 2	Released cultivar in Myanmar (1984/85)

Continued from previous page

ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
Robut 33-1		Sinpadetha 3	Released cultivar in Myanmar (1984/85)
Sel. from Robut 33-1		Johari	Released cultivar in Tanzania (1985)
ICGV 87123	ICGS 11	ICGS 11	Released cultivar in central and peninsular India for postrainy season (1986)
TMV 7 x FSB 7-2		VRI 1	Released cultivar in Tamil Nadu state, India (1986)
ICG 7886	Tifrust 2	Cardi-Payne	Released germplasm line in Jamaica (1987)
ICGV 87127	ICGS 35	Jinpungtangkong	Released cultivar in South Korea (1987)
FESR selection		ALR 1	Released rust-resistant cultivar in Tamil Nadu state, India (1987)
ICG 7794	ICG 7794	Roba	Released cultivar in Ethiopia (1988)
ICGV 87128	ICGS 44	ICGS 44	Released cultivar in Gujarat state, India for postrainy season (1988)
(ICGV 87128+ICGV 87187) bulk		BARD 699	Released cultivar in Pakistan (1989)
ICGV 87141	ICGS 76	ICGS 76	Released cultivar in states of Andhra Pradesh, Karnataka, and parts of Maharashtra and Tamil Nadu in India for rainy season (1989)
X 14-4-B-19-B x NC Ac 17090		Girnar 1	Released cultivar in India (1989)
Robut 33-1 x NC Ac 2821		RG 141	Released cultivar in Rajasthan state, India (1989)
ICGV 87119	ICGS 1	ICGS 1	Released cultivar in northern India (1990)
ICGV 87121	ICGS 5	ICGS 5	Released cultivar in U.P. state, India (1989)
ICGV 87187	ICGS 37	ICGS 37	Released cultivar in states of Gujarat, Madhya Pradesh and northern Maharashtra, India for postrainy season (1990)
ICGV 87160	ICG(FDRS)10	ICG(FDRS)10	Released cultivar in peninsular zone, India, 1990
ICGMS 42		CG 7 MGS 4	Released cultivar in Malawi in 1990 Released cultivar in Zambia in 1990
ICGV 86194	ICGS 114	Sinkarzei	Released cultivar in Ghana (1989)
ICGV 86590		ICGV 86590	Released cultivar in southern Maharashtra, parts of Andhra Pradesh, Tamil Nadu, Karnataka and Kerala states in India for rainy season (1991)

ICRISAT material not released but grown by farmers.

ICRISAT name/Source/ Parent/Pedigree	Other name/s	Release name	Remarks
Sorghum			
ICSV 745		ICSV 745	Adopted by farmers in Karnataka state, India (1991)
ISIAP Dorado		Dorado	Grown by farmers in Paraguay
Pigeonpea			
ICPL 84045		ICPL 84045	Grown by farmers in Sri Lanka (1991)
Groundnut			
ICGS 21		ICGS 21	Grown by farmers in Maharashtra state, India
ICGV 86564	ICG(CG)49	ICGS 49	Grown by farmers in Maharashtra and Tamil Nadu states, India
ICG(FDRS) 4		ICG(FDRS) 4	Grown by farmers in Maharashtra state, India

Appendix Table 2. Number of sorghum and pearl millet varieties grown before and after SADC/ICRISAT SMIP was established.[1]

Country	Before SMIP (1983)		After SMIP (1992)	
	Sorghum	Pearl millet	Sorghum	Pearl millet
Angola	0	0	0 (0)[2]	0 (0)[2]
Botswana	3	1	4 (0)	1 (0)
Lesotho	2	0	2 (0)	0 (0)
Malawi	2	0	4 (1)	1 (0)
Mozambique	0	0	5 (4)	1 (0)
Namibia	1	0	1 (0)	1 (1)
Swaziland	1	0	3 (2)	0 (0)
Tanzania	4	1	5 (1)	1 (0)
Zambia	0	0	5 (5)	2 (2)
Zimbabwe	4	1	8 (3)	2 (1)
Total	17	3	37 (17)	9 (4)

1. Includes extensively grown varieties only, not all released varieties.
2. Number of ICRISAT materials indicated in paretheses.

Appendix 3. ICRISAT's Proposed Thematic Research Priorities for 1994-1998

(a) Core funding

Rank	Program	Center(s)/location(s)	Constraint/theme	Efficiency			Research cost		Equity		Inter-nation-ality	Sust-aina-bility	Comp-osite index	Cum-ulative Cost
				NPV ($mill)	Net B/C ratio	IRR %	First yr ($mill)	Av'ge 94-98 ($mill)	Poverty million poor	Gender million fem ll				
1	GRU	IC	Germplasm evaluation	79.1	101.9	-	0.19	0.13	397.0	378.0	1.00	4	5.21	0.19
2	GRU	IC	Germplasm collection	24.5	40.7	-	0.14	0.12	397.0	378.0	1.00	5	4.84	0.33
3	LGM	IC	Drought-CP	265.2	113.7	47.3	0.48	0.42	80.6	119.5	0.55	3	3.64	0.81
4	GRU	IC	Germplasm maintenance	15.3	35.5	-	0.10	0.09	397.0	378.0	1.00	3	3.63	0.91
5	LGM	IC	Ascochyta blight-CP	73.2	134.7	64.0	0.14	0.09	9.9	74.4	0.57	1	3.48	1.05
6	LGM	IC/ISC/SADC	Rust-GN	80.9	47.9	33.0	0.33	0.28	337.0	310.0	0.70	3	3.35	1.38
7	LGM	IC	Aflatoxin-GN	7.8	23.1	29.3	0.05	0.04	248.2	298.6	0.82	5	3.28	1.43
8	LGM	IC/ISC/SADC	Late leaf spot-GN	32.7	12.4	24.9	0.43	0.36	329.0	302.0	0.84	4	3.00	1.86
9	LGM	IC/ISC	Aflatoxin (mgt)-GN	19.7	6.4	23	0.56	0.47	380.0	306.0	0.80	5	2.96	2.42
10	LGM	IC	Insect damage-CP	76.1	78.5	47.2	0.25	0.16	88.2	107.9	0.26	4	2.94	2.67
11	LGM	IC	Wilt-CP	63.9	114.2	57.0	0.14	0.09	88.2	107.9	0.28	1	2.90	2.81
12	RMP	IC	Adoption assess't/impact evl.	-	-	-	0.62	0.52	75.9	114.1	-	3	-	3.43
13	RMP	IC	Res. resource allocation	-	-	-	0.21	0.11	397.0	378.0	1.00	4	-	3.64
14	RMP	IC	Soil nutrients	130.3	35.9	43.4	0.54	0.45	167.9	162.2	0.49	5	2.81	4.18
15	LGM	IC/ISC/SADC	Early leaf spot-GN	9.1	4.4	21.3	0.45	0.37	346.0	313.0	0.70	4	2.75	4.63
16	LGM	IC/EARCAL	Genetic potential yield-PP	64.0	63.5	41.5	0.13	0.11	125.2	166.2	0.23	3	2.63	4.76
17	LGM	IC/ISC/SADC	Low yield potential-GN	29.8	12.3	23.4	0.44	0.37	234.2	363.4	0.71	3	2.53	5.20
18	CRL	IC/WASIP/EARCAL/SADC	*Striga*-SG	78.7	41.4	46.2	0.28	0.23	31.5	43.6	0.80	4	2.51	5.48
19	LGM	IC/ISC/SADC	Drought-GN	14.5	5.2	20.3	0.50	0.42	331.8	326.0	0.62	3	2.43	5.98
20	LGM	IC	Root rots-CP	41.3	70.3	49.1	0.14	0.09	88.2	107.9	0.33	2	2.34	6.12
21	LGM	IC	Bud necrosis virus-GN	1.0	1.2	13.9	0.13	0.11	[illegible]	328.1	0.66	3	[illegible]	6.25
22	CRL	IC/WASIP/SADC	Grain & stover yield-SG	47.1	16.6	31.7	0.68	0.57	180.8	169.2	0.85	3	2.33	6.93
23	RMP	ISC/WASIP(N)	Soil fertility	86.4	21.1	29.1	0.58	0.48	16.8	37.9	0.78	5	2.28	7.51
24	LGM	IC	Sterility mosaic/fusar. wilt-PP	58.5	40.4	33.5	0.21	0.17	125.2	168.2	0.12	4	2.21	7.72
25	RMP	IC	Soil structure	29.4	5.9	22.8	0.74	0.62	167.9	162.2	0.48	5	2.18	8.46
26	LGM	IC	Leaf miner-GN	5.7	6.0	20.8	0.19	0.16	195.7	268.6	0.46	4	2.17	8.65
27	LGM	IC	Biological N fixation-CP	9.8	16.6	30.4	0.10	0.09	88.2	133.7	0.43	5	2.16	8.75
28	LGM	IC	Leaf miner (mgt)-GN	4.8	4.5	21.3	0.23	0.19	195.7	268.6	0.46	4	2.14	8.98
29	RMP	IC	Water deficit	122.8	19.1	32.9	0.95	0.79	154.4	151.4	0.34	4	2.03	9.93
30	LGM	IC	*Spodoptera*-GN	0.7	0.9	13.3	0.14	0.12	174.7	247.6	0.40	4	1.90	10.07
31	LGM	IC	Peanut clump virus-GN	5.7	4.9	21.0	0.23	0.19	114.3	124.0	0.84	3	1.87	10.30
32	LGM	IC/ISC/SADC	Rosette virus-GN	20.8	8.6	23.1	0.53	0.39	71.9	71.4	0.89	3	1.82	10.83
33	LGM	IC	*Helicoverpa* (mgt)-PP	26.0	23.8	29.7	0.17	0.14	98.2	136.4	0.17	4	1.82	11.00
34	CRL	IC/WASIP/EARCAL/SADC	Stem borer-SG	8.4	1.6	16.1	0.76	0.63	232.7	191.2	0.75	2	1.82	11.76
35	CRL	IC/WASIP/EARCAL	Grain mold-SG	66.0	21.5	32.2	0.45	0.38	51.2	57.2	0.68	3	1.81	12.21
36	LGM	ISC	Millipedes-GN	3.0	8.0	23.8	0.04	0.03	27.3	37.2	0.77	4	1.80	12.25
37	RMP	ISC/WASIP(N)	Water deficit-PM,SG,GN	22.0	3.9	19.4	0.83	0.69	24.1	42.6	0.76	4	1.71	13.08
38	RMP	ISC/WASIP(M,N)	Tech. adoption/impact evl.	-	-	-	0.29	0.24	24.1	42.6	0.83	2	-	13.37
39	RMP	ISC/WASIP	Agroforestry	16.7	3.5	17.7	0.60	0.56	24.1	42.6	0.76	4	1.70	13.97
40	RMP	ISC/WASIP(N)	Char'n of prod'n environment	-	-	-	0.72	0.60	24.1	42.6	0.76	3	-	14.69
41	LGM	IC	Nematodes-GN,PP,CP	15.1	5.9	21.3	0.41	0.34	179.7	283.9	0.27	3	1.89	15.10
42	LGM	ISC	Termites-GN	2.3	2.4	16.7	0.11	0.09	27.3	37.2	0.77	4	1.86	15.21
43	LGM	IC	Sub-optimal yield-CP	0.9	0.5	12.6	0.25	0.21	88.2	133.7	0.52	4	1.88	15.46
44	CRL	EARCAL	Low temperature-SG	1.6	9.8	13.4	0.19	0.17	32.7	11.8	0.80	4	1.83	15.65
45	LGM	ISC	White grubs-GN	1.3	1.6	15.8	0.11	0.09	27.3	37.2	0.72	4	1.82	15.76
46	CRL	IC/WASIP	Head bug-SG	12.8	7.1	24.7	0.27	0.22	43.2	74.8	0.76	3	1.81	16.03
47	LGM	IC/EARCAL	Drought-PP	19.7	7.7	24.0	0.41	0.35	98.2	136.4	0.28	4	1.81	16.44
48	CRL	IC/WASIP/EARCAL/SADC	Anthracnose-SG	13.5	4.6	25.5	0.43	0.36	126.7	110.8	0.82	2	1.80	16.87
49	CRL	IC/WASIP/EARCAL	Midge-SG	14.4	4.1	19.4	0.52	0.43	66.6	47.1	0.82	3	1.59	17.39
50	RMP	IC	Char'zation of environment	-	-	-	0.25	0.21	75.9	114.1	-	3	-	17.64
51	RMP	IC/EARCAL	Micro-economics studies	-	-	-	0.41	0.41	-	-	-		-	18.05
52	RMP	IC	Natural resources	-	-	-	0.60	0.50	75.9	114.1	-	5	-	18.65
53	RMP	IC	Supply & demand	-	-	-	0.21	0.17	75.9	114.1	-	4	-	18.86
54	RMP	IC	Farmers' preferences	-	-	-	0.14	0.12	75.9	114.1	-	3	-	19.00
55	RMP	IC	Beneficial organisms	27.3	11.3	27.4	0.41	0.34	82.4	104.9	0.27	4	1.55	19.41
56	RMP	SADC	Plant nutrition-SG/PM/FM	4.5	13.0	28.0	0.08	0.07	32.1	12.4	0.70	3	1.54	19.49
57	LGM	IC	Peanut mottle virus-GN	3.9	3.5	18.6	0.21	0.18	147.3	138.7	0.91	1	1.51	19.70

Rank	Program	Center(s)/location(s)	Constraint/theme	Efficiency			Research cost		Equity		Internationality	Sustainability	Composite index	Cumulative Cost
				NPV ($ mill)	Net B/C ratio	IRR %	First yr ($ mill)	Av/ge 94-98 ($ mill)	Poverty million poor	Gender million fem ll				
58	RMP	ISC/WASIP(M)	Consumer/demand studies	-	-	-	0.21	0.17	24.1	42.6	0.78	2	-	19.91
59	CRL	LASIP	Acid soil adaptation-SG	11.5	9.1	29.1	0.19	0.19	48.9	20.5	0.64	3	1.45	20.74
60	CRL	IC/ISC/EARCAL/SADC	Drought-PM	33.7	8.9	26.8	0.58	0.47	65.5	116.7	0.48	3	1.48	20.47
61	GIP	SADC	Lack of adaptability-GN	20.0	33.9	38.4	0.08	0.07	12.9	12.4	0.75	1	1.47	20.56
62	LGM	IC	Peanut clump virus-GN	4.5	4.3	20.7	0.18	0.15	97.1	47.1	0.54	3	1.40	20.92
63	RMP	SADC	Drought-SG,PM,FM	4.9	8.1	25.1	0.14	0.12	32.1	12.4	0.65	3	1.40	21.06
64	CRL	IC/ISC/EARCAL/SADC	Downy mildew-PM	75.2	16.8	34.8	1.12	0.89	64.1	114.6	0.23	3	1.39	22.18
65	CRL	IC/WASIP/EARCAL/SADC	Drought-SG	30.3	8.6	28.8	0.85	0.71	31.4	229.7	0.76	1	1.38	23.03
66	CRL	IC/EARCAL/SADC	Leaf blight-SG	9.6	5.0	14.2	0.33	0.28	37.4	52.0	0.86	2	1.37	23.36
67	CRL	EARCAL	Blast disease-FM	3.8	13.8	15.0	0.33	0.29	80.0	23.1	0.68	2	1.36	23.69
68	CRL	ISC	*Striga*-PM	10.7	4.8	22.4	0.33	0.28	10.7	31.1	0.66	3	1.33	24.02
69	CRL	IC/ISC	Low grain yld-PM	59.4	10.5	40.0	0.87	0.71	55.4	93.6	0.32	3	1.30	24.89
70	LGM	IC	Phytophthora blight (mgt)-PP	9.2	15.9	33.2	0.12	0.09	103.9	147.4	0.01	3	1.28	25.01
71	LGM	IC	*Helicoverpa*-PP	1.8	0.8	12.9	0.32	0.27	98.2	136.4	0.08	4	1.27	25.33
72	CRL	LASIP	Foliar disease resistance-SG	5.8	3.3	20.0	0.41	0.41	71.9	23.3	0.50	3	1.25	25.74
73	SMIP	SADC	Improvement of grain yield-FM	4.0	5.6	22.0	0.21	0.14	13.1	6.8	0.65	3	1.20	25.95
74	ECO	SADC	Impact assessment-SG,PM,FM	-	-	-	0.12	0.07	11.9	4.6	0.48	1	-	26.07
75	ECO	SADC	Policy analysis-SG,PM,FM	-	-	-	0.12	0.10	85.7	34.4	0.76	1	-	26.19
76	CRL	IC	Shoot fly-SG	22.5	12.4	26.2	0.27	0.22	45.6	67.3	0.49	2	1.19	26.46
77	CRL	IC	Lack of adaptability (arid)-PM	12.5	9.9	38.3	0.66	0.25	20.5	68.7	0.83	3	1.18	27.12
78	LGM	IC	*Maruca*-PP	0.7	1.9	15.4	0.06	0.05	52.5	102.4	0.61	4	1.17	27.18
79	LGM	IC	Stunt virus-CP	0.8	1.1	14.4	0.10	0.09	88.2	107.9	0.85	3	1.13	27.28
80	LGM	IC/EARCAL	Podfly (mgt)-PP	7.5	8.0	23.3	0.14	0.12	70.4	130.0	0.88	3	1.10	27.42
81	LGM	IC	Waterlogging-PP	12.6	7.0	23.4	0.30	0.25	89.4	125.7	0.85	3	1.08	27.72
82	LGM	IC/EARCAL	Podfly-PP	0.5	0.5	12.0	0.14	0.12	70.4	130.0	0.80	3	1.07	27.86
83	CRL	IC/ISC	Head caterpillars-PM	8.0	4.0	22.3	0.30	0.25	10.3	27.5	0.89	2	0.99	28.16
84	CRL	IC/ISC	High temperature-PM	15.5	5.9	25.8	0.50	0.41	58.8	113.6	0.29	2	0.96	28.66
85	LGM	IC	Cold tolerance-CP	9.2	7.6	25.1	0.23	0.21	20.2	66.1	0.83	3	0.83	28.89
86	CRL	IC/SADC	Forage sorghum-SG	12.2	9.9	39.2	0.25	0.19	84.2	72.3	0.28	1	0.77	29.14
87	CRL	IC/ISC	Stem borers-PM	2.1	1.1	15.1	0.29	0.24	2.5	23.8	0.44	2	0.76	29.43
88	LGM	IC	Botrytis gray mold-CP	2.7	2.9	18.3	0.19	0.16	30.1	82.8	0.48	1	0.74	29.62
89	ECO	SADC	Seed distribution-SG,PM,FM	-	-	-	0.19	0.10	14.8	5.5	0.85	2	-	29.81
90	ECO	SADC	Market reform-SG,PM,FM	-	-	-	0.17	0.11	20.5	10.5	0.72	1	-	29.98
91	RMP	IC	Institut'l & human resources	-	-	-	0.12	0.10	75.9	114.1	-	4	-	30.10
92	RMP	IC	Input markets	-	-	-	0.08	0.06	75.9	114.1	-	2	-	30.18

(b) Complementary funding

Rank	Program	Center(s)/location(s)	Constraint/theme	Efficiency			Research cost		Equity		Internationality	Sustainability	Composite index	Cumulative Cost
				NPV ($ mill)	Net B/C ratio	IRR %	First yr ($ mill)	Av/ge 94-98 ($ mill)	Poverty million poor	Gender million fem ll				
93	COU	IC/SADC/EARCAL/WASIP	Product quality-SG	28.0	36.9	36.8	0.13	0.11	185.7	169.2	0.79	3	2.68	30.31
94	RMP	ISC/WASIP	Weeds	14.6	6.5	21.7	0.33	0.28	24.1	42.6	0.76	3	1.51	30.64
95	RMP	SADC	Weed (mgt)-SG,PM,FM	8.6	10.0	26.7	0.21	0.17	32.1	12.4	0.72	3	1.50	30.85
96	CRL	LASIP	Acid soil adaptation-SG	11.5	9.1	29.1	0.23	0.19	48.9	20.5	0.69	3	1.45	31.08
97	LGM	ISC	Aphids-GN	0.2	0.1	13.1	0.18	0.15	27.3	37.2	0.77	3	1.39	31.26
98	RMP	SADC	Nematodes-SG	0.8	2.2	17.5	0.09	0.08	5.8	1.6	0.53	4	1.34	31.35
99	LGM	EARCAL/Malawi	Crop improvement-PP	7.8	2.2	18.7	0.83	0.69	23.0	14.5	0.73	3	1.34	32.17
100	CRL	SADC/WASIP	Sooty stripe-SG	0.2	0.2	11.1	0.17	0.14	22.9	40.6	0.78	2	1.15	32.34
101	CRL	WASIP/EARCAL	Long smut-SG	5.5	4.7	20.5	0.17	0.14	4.4	7.9	0.71	2	1.08	32.51
102	SMIP	SADC	Storage pests-SG,PM	0.0	(0.1)	9.5	0.12	0.10	17.3	9.7	0.48	3	1.03	32.63
103	CRL	ISC	Low grain yield-PM	6.7	5.5	25.0	0.21	0.18	11.5	29.6	0.32	3	1.00	32.84
104	SMIP	SADC	Ergot-SG	1.9	4.0	25.0	0.18	0.10	13.7	5.5	0.68	1	0.80	33.02
105	GIP	SADC	Improved c'vars conlec.-GN	7.5	8.2	25.1	0.17	0.14	3.9	3.0	0.55	1	0.73	33.19
106	SMIP	SADC	Photosensitive-PM	1.0	3.0	17.2	0.08	0.07	2.8	3.8	0.00	3	0.57	33.27
107	SMIP	SADC	Photosensitive-SG	0.3	3.9	20.0	0.02	0.01	3.8	3.8	0.30	1	0.30	33.29
108	COU	SADC	Quality, screening-SG,PM,FM	-	-	-	0.17	0.14	17.3	7.1	0.54	1	-	33.46
109	COU	SADC	Quality imp'ment'n-SG,PM,FM	-	-	-	0.05	0.04	17.3	7.1	0.54	3	-	33.51
110	COU	SADC	Sweet stem sorghum-SG	-	-	-	0.14	0.12	15.9	6.9	0.44	4	-	33.65

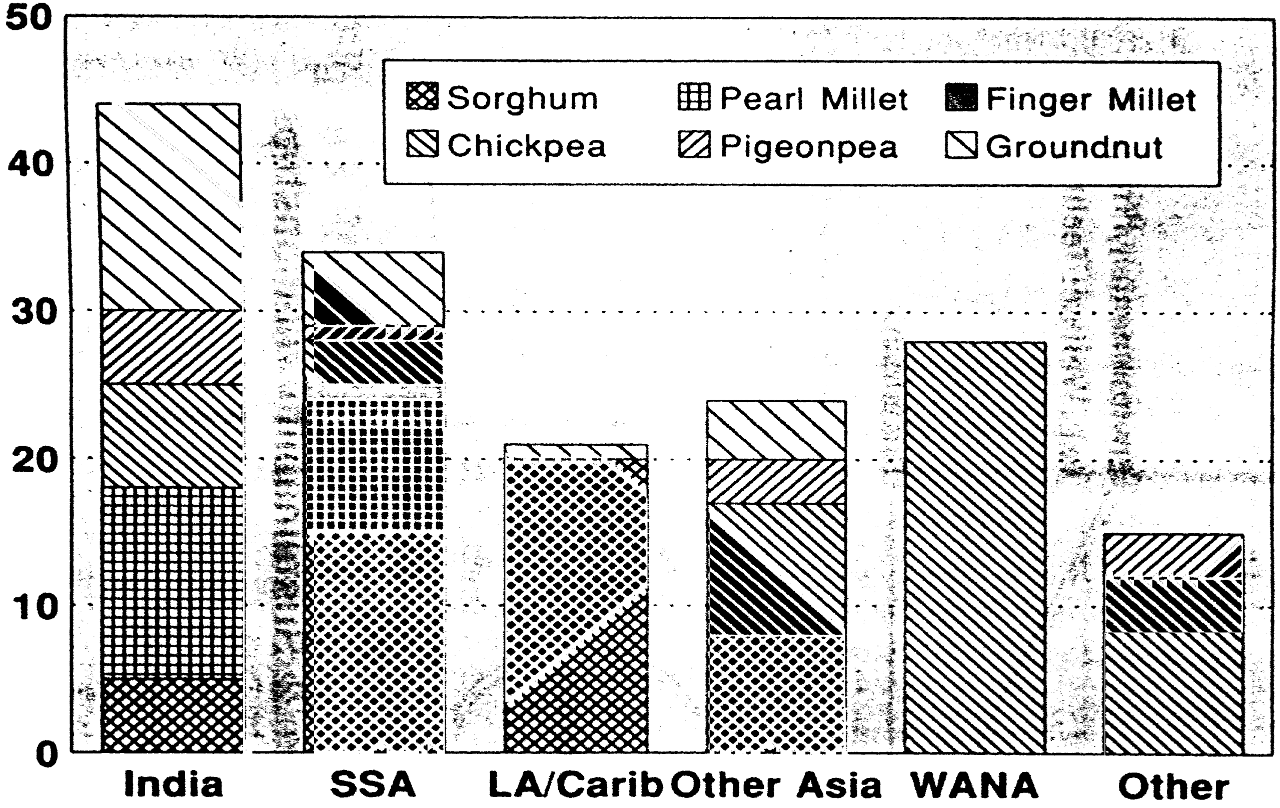


Figure 1. Regional pattern of releases of ICRISAT cultivars

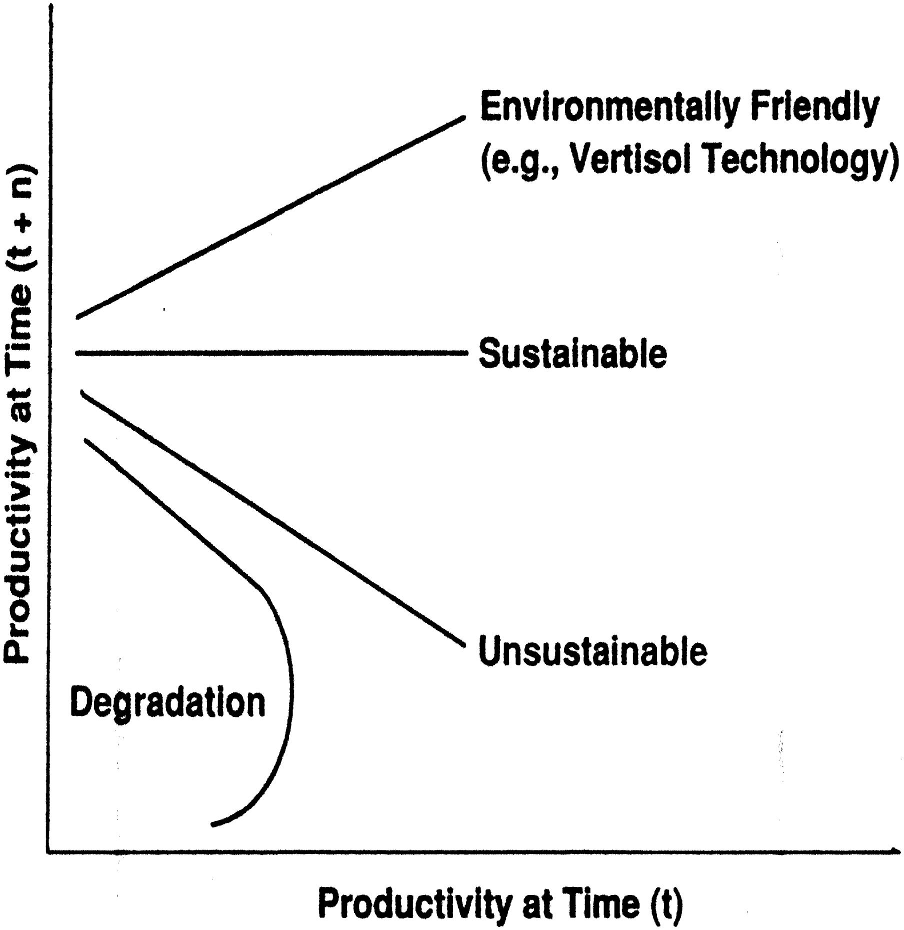
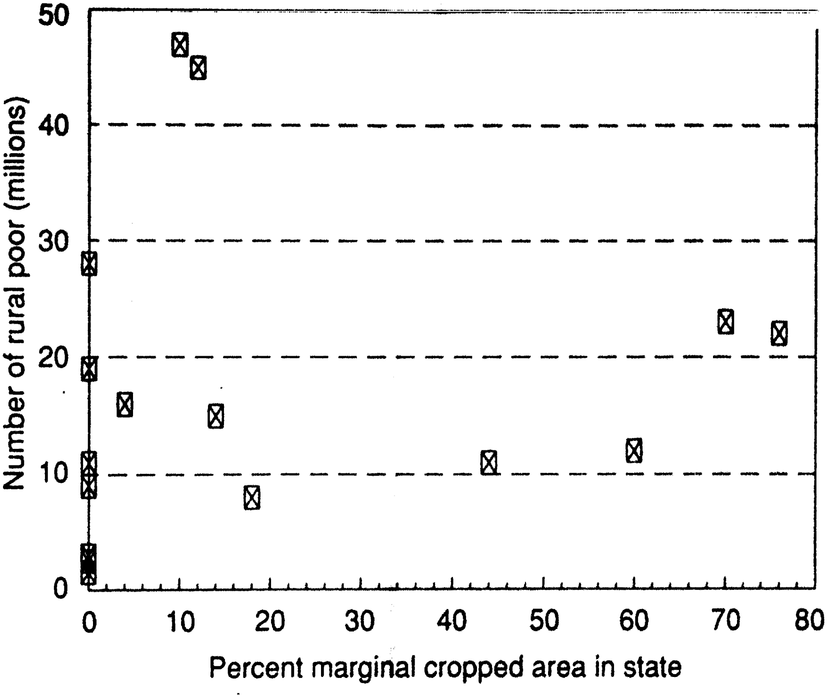


Figure 2. Sustainability relationships



Source: Kelley and Rao (1992)

Figure 3. Poverty in marginal indian regions.

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