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Conventional Cropping Systems for Alfisols and Some Implications for Agroforestry Systems

R.W. Willey, M.S. Reddy, and M. Natarajan[1]

Abstract

ICRISAT's work on conventional annual cropping systems for Alfisols is summarized, and the implications for agroforestry systems examined. The importance of intercropping system is emphasized as a means of increasing cropping intensity above that of a sole crop. Data from sorghum/pigeonpea and millet/groundnut intercropping systems are presented to illustrate the concepts of "temporal" and "spatial" complementarity between crops. It is reasoned that both these concepts are equally applicable in agroforestry systems. Experiments on sorghum/groundnut are presented to indicate the possibilities of greater relative advantages of intercropping systems under conditions of moisture stress. But the dangers of increasing total plant populations under such conditions (e.g., by adding a tree species) are also highlighted. The limitations on nitrogen contributions from annual grain legumes used as intercrops are discussed, and it is suggested that there might be scope for much greater contributions from leguminous trees in agroforestry systems. The possibilities of improved pest or disease control, and of greater yield stability in intercropping systems are described, and again the implications for agroforestry systems are considered.

Introduction

Drawing largely on ICRISAT's work, this paper discusses cropping systems of conventional annual crops. The wider aim of the paper, however, is to consider the implications for alternative land-use systems, i.e., systems incorporating perennial shrub or tree species. Current interest in these agroforestry systems stems mainly from the fact that they place greater emphasis on the production of fuel and fodder-products that are becoming increasingly scarce in the developing world, but seldom seriously considered in the development of improved conventional systems. A further feature—potentially very important for Alfisols—is that these agroforestry systems can provide large amounts of crop material that can be used for various soil amelioration purposes, as a mulch, for instance, or incorporated into the soil for improvement of nutritional or physical properties.

ICRISAT has not made any studies, to date, on agroforestry systems. Hence, this paper does not directly focus on them. What is attempted here is an analysis of some aspects of conventional systems to examine how far the basic concepts can be extended to agroforestry systems. The paper also tries to highlight those areas in which agroforestry systems may have most to offer.

Sole-crop or Intercropping Systems

With any cropping system a major objective should be to provide a continuum of efficient crop growth for as long a cropping period as possible. On the SAT Alfisols, the potential cropping period is deter-

1. Farming Systems Research Program (now Resource Management Program), ICRISAT, Patancheru, A P. 502 324, India

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mined largely by moisture supply. The objective of a cropping system is, therefore, to start crop growth as early as feasible at the beginning of the rains and to continue it for as long after the rains as the limited soil moisture storage will allow. With conventional annual crops, this potential cropping period for most SAT Alfisols is about 120-150 days.

Traditional crops are usually well adapted to this cropping period, flowering towards the end of the rainy season and maturing on the stored soil moisture. But in agricultural terms, growth is not necessarily efficient: the traditional cereal genotypes of this growing period produce large amounts of vegetative material but little grain. Such slower-growing crops as pigeonpea and castor—which make very efficient use of residual moisture—make very inefficient use of resources in the early part of the season. Some of those inefficiencies have been reduced, and yields increased with improved early-maturing genotypes. In theory, these early genotypes also provide scope for further cropping, but, with the limited growing period on Alfisols, this becomes difficult. Sequential systems of two full crops are seldom possible unless at least one of them is a short-season catch crop and, thus, of low-yield potential. At ICRISAT, it has been possible to grow a catch crop of the hardy horse gram after an early pearl millet, or a very early mung bean before a castor crop. But in both these systems the additional returns, compared with that from the single crop, have been small (Table 1). Relay cropping, i.e., sowing of the second crop 2-3 weeks before harvest of the first one, may improve the probability of producing two crops. At ICRISAT both the previous examples of sequential systems were grown as relay systems as well (Table 1). However, relay systems can present considerable practical difficulties in terms of sowing the second crop in the standing first crop, and in harvesting the first crop while seedlings of the second crop are present. With some crops it is possible to harvest a shorter season ratoon crop after the main crop. One such crop—sorghum—however produced very poor and erratic ratoon yields on Alfisols at ICRISAT (Table 1), but pigeonpea may hold out better possibilities.

To summarize the difficulties with sole-crop systems for Alfisols, there may often be more than enough moisture to produce one crop but not enough to produce two. In this situation, intercropping systems can often provide the means of at least increasing the cropping intensity over that of a single crop. Three typical Alfisol intercropping combinations—sorghum/pigeonpea, millet/groundnut, and pigeonpea/groundnut—averaged over 3 years, produced higher returns compared to sole-crop systems (Table 1). The mechanisms whereby these intercrops are able to achieve higher yields have considerable implications for agroforestry systems. A brief discussion on these mechanisms follows.

Intercropping Systems

Figure 1a shows the mean dry-matter accumulation and yields produced during a 2-year experiment at ICRISAT on sorghum/pigeonpea. The sorghum was an improved early hybrid of about 90 days, and the pigeonpea an improved genotype maturing in about 170 days on Alfisols. Fertilizer application was at a reasonably high level. Sorghum is usually regarded as the main crop in this system. The planting pattern was 2 rows sorghum to 1 row pigeonpea. The population of each crop was equivalent to its full sole-crop optimum. Growth and yield of the intercrop sorghum was a little less than that of sole sorghum, and the final grain yield averaged was 83% that of the sole crop. The slow growth of the pigeonpea in the early stages was further suppressed by the sorghum in the intercrop, but, at final harvest, it was still able to produce quite a large amount of dry matter—62% of the sole-crop dry matter. Moreover, because the early sorghum competition only reduced the vegetative growth, the harvest index of the intercrop pigeonpea was higher (30.1%) than that of the sole crop (25.9%). The net result was that the grain yield of intercrop pigeonpea was 72% of the sole-crop yield. Taking sorghum as the main crop, therefore, a sacrifice of 17% in yield of this crop allowed an additional 72% in pigeonpea yield. (The 5-year average for this combination over several agronomic experiments has been an 89% sorghum yield and a 59% pigeonpea yield.)

The use of resources in this combination is illustrated by the light interception pattern shown in Fig. 1b. Again, compared with sole sorghum, light interception in the intercrop's early stages was only slightly reduced by the presence of pigeonpea rows; and, after sorghum was harvested, the intercrop pigeonpea ensured the interception of more light at the end of the season. Total dry-matter accumulation in the intercrop was directly proportional to the total amount of light energy intercepted. Therefore, the greater yield of the intercropping system could be wholly attributed to its interception of more light. Vertisol experiments with this combination have

Table 1. Cropping systems on Alfisols at ICRISAT Center (means of 1978, 1979, and 1980).

Cropping systems	Grain yield ($kg\ ha^{-1}$)				Net monetary returns[1] ($Rs\ ha^{-1}$)			
	1978	1979	1980	Mean	1978	1979	1980	Mean
Sole castor	1462	1144	1038	1215	2039	2814	2305	2386
Sole groundnut	1236	1173	1168	1192	1133	2211	3659	2334
Sole sorghum	2516	2241	2826	2528	1402	1406	3628	2145
Sole pearl millet	1940	2099	1875	1971	1158	1915	1781	1618
Sole pigeonpea	-	1221	1013	1117	-	2745	2578	2662
Sorghum/pigeonpea intercrop (2 1)	2169/417	1680/831	2391/634	2080/627	1873	2855	4648	3125
Millet/groundnut intercrop (1 3)	849/869	1063/881	1292/747	1068/832	1293	2681	3610	2528
Pigeonpea/groundnut intercrop (1 4)	-	844/841	769/926	807 884	-	3366	4826	4096
Mung bean + relay castor	634+885	603+737	570+292	602+638	2075	3393	2026	2498
Mung bean + sequential castor	593+672	569+613	-	581+643	1766	2928	-	2347
Millet + relay horse gram	1866+594	2099+536	-	1983+565	1412	2181	-	1797
Millet + sequential horse gram	1940+616	-	1875+376	1908+496	1583	-	2166	1875
Sorghum + ratoon sorghum	2516+505	-	2826+237	2671+371	1511	-	3689	2600
LSD (0 05)					304	399	430	
SE (mean)					103	135	146	
CV (%)					11 39	9 04	7 95	

1 These are gross returns less the cost of seeds fertilizers, and pesticides Prevailing market prices (Rs 100 kg) 1 month after the harvest of the respective crops used for calculating gross returns for 1978-79, 1979-80 and 1980 81 were respectively castor 170, 185, and 265, groundnut 150, 250, and 375, sorghum 80 90, and 150, millet 80, 110, and 116 pigeonpea 230, 260 and 297, mung bean 200, 330, and 342, horsegram 100 102 and 177

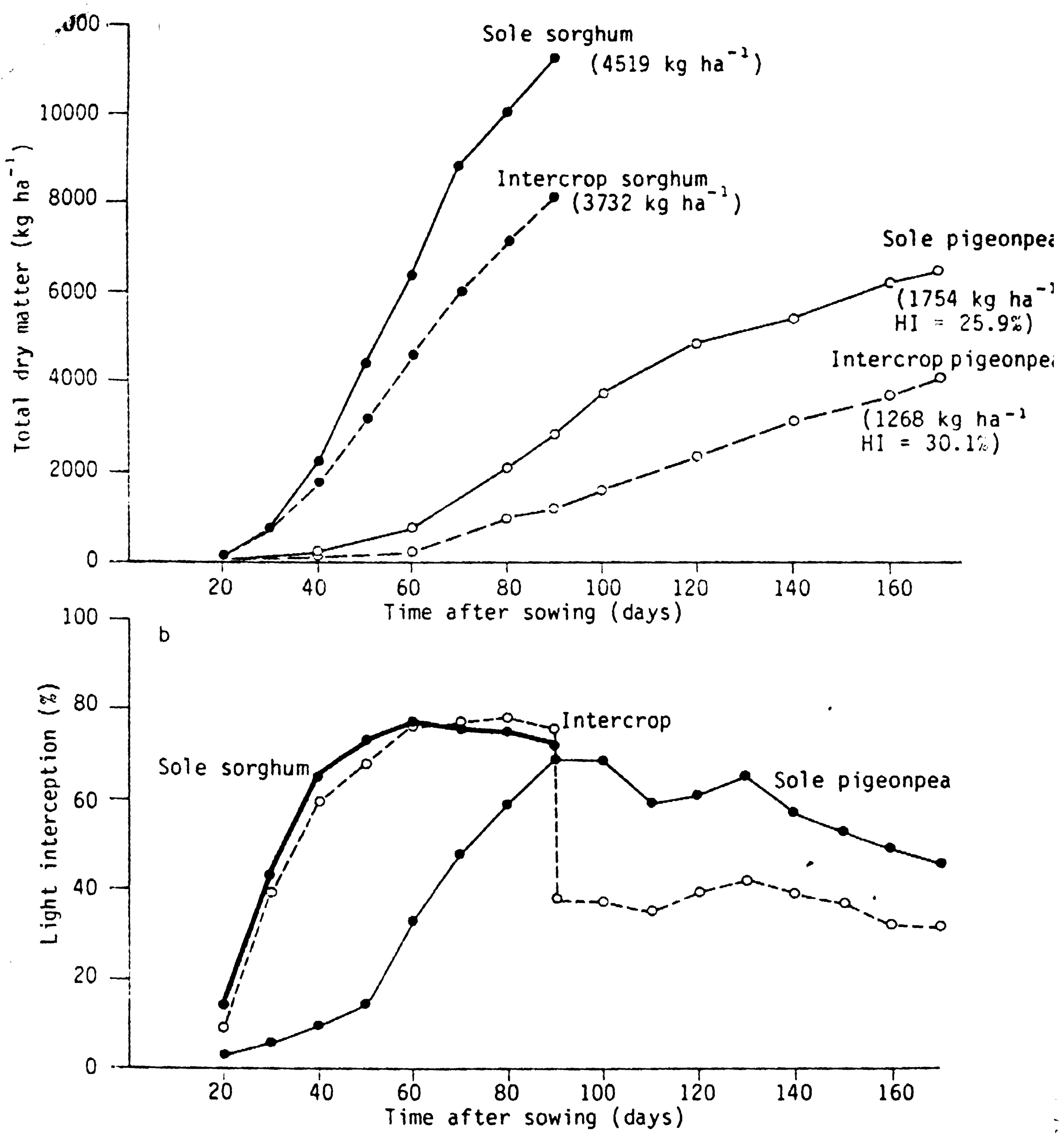

Figure 1. Dry-matter accumulation (a) and light-interception (b) patterns with sorghum and pigeonpea in sole and intercrop systems on Alfisols at ICRISAT Center (means of 1979 and 1981).

indicated similar effects for water use and nutrient uptake (Natarajan and Willey 1981).

In simple terms, therefore, this combination displays the classic "temporal" complementarity between an early, fast-growing component that ensures use of early resources, and a later-maturing component that ensures use of later resources. This complementarity has considerable implication for agroforestry systems because it emphasizes that, if the growing period can be extended still further with deeper-rooting trees able to tap more moistu there is scope for further increasing overall prod

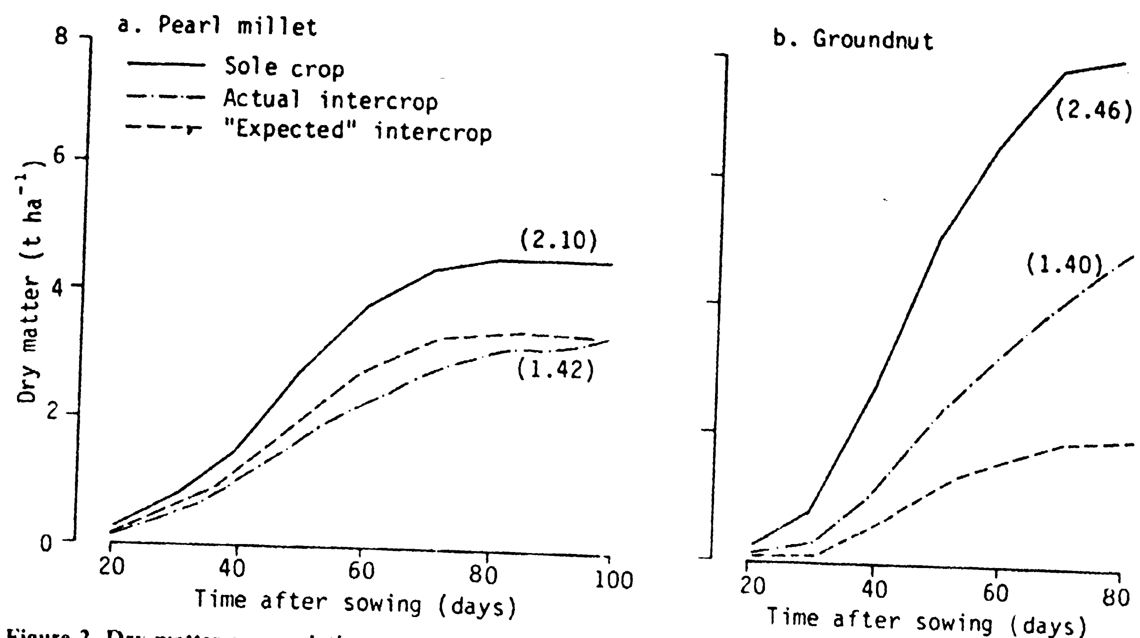

Figure 2. Dry-matter accumulation compared with sole crops in a 1:3-row combination of pearl millet and groundnut at ICRISAT Center (means of 1978, 1979, and 1980). Seed/pod yields (t ha^{-1}) are given in parentheses.

tivity. However, this simple concept of greater resource use due to temporal differences between crops gives no insight into the possible interactions that can occur at times of the season when two or more components are simultaneously making active demands on resources. Results with the millet/groundnut combination illustrate some of these possible effects.

Figure 2 shows the dry-matter accumulation and yields, averaged over 3 years, of a 1:3-row combination of millet and groundnut in which the total population was equivalent to a full sole-crop population. The groundnut suffered some competition during the peak growth period of the millet, but the final yield per plant was very similar to that in sole cropping. Thus, yield per unit area was closer to the "expected" 75% sole-crop yield (Fig. 2b). In contrast, yield per plant of the highly competitive millet more than doubled in intercropping. Hence, yield per unit area was well above the "expected" 25% sole-crop yield (Fig. 2a). The overall yield advantage of intercropping was 35% for total dry matter, and 25% for grain. (The average grain yield advantage for this combination, as revealed by several agronomic experiments over a 5-year period, was 31%).

Unlike the temporal sorghum/pigeonpea combination that gives greater productivity simply by utilizing more resources, this millet/groundnut showed evidence of greater efficiency of resource use. This was especially so for light: each unit of intercepted light produced 26% more dry matter than expected from sole-crop efficiencies. There was also some evidence of improved water-use efficiency, partly because of reduced evaporation losses and partly because more dry matter was produced per unit of water transpired (Vorasoot 1982). Nutrient use, however, was similar to sorghum/pigeonpea in that the higher yield from intercropping was associated with a commensurately higher uptake of nutrients.

Insofar as these millet/groundnut results can be extrapolated to other crops, they provide some important pointers for agroforestry systems. They clearly show that a combination of different crop canopies may provide greater efficiency of light use. It is possible, of course, that the greater efficiency in millet/groundnut is due to the combination of a C4 and C3 species, in which case there might be no further improvement by adding a tree species. But it is also possible that the improved efficiency is simply due to better dispersion of the whole canopy, in which case an additional, taller species might confer additional benefits; indeed there is a general belief that more efficient use of light is one of the advantages of "multistorey" systems involving tree species (Nelliat et al. 1974).

There are similar implications for the water resource, although the millet/groundnut results suggest that, while there is some improvement in efficiency of water use, at the same time there may be greater demand for water in the soil profile. But whether this will necessarily result in increased stress on the crop components will depend on the extent to which one component may be able to utilize some water resource not available to another component. Clearly, where an additional tree species is able to utilize deeper profile water not accessible to conventional crops, a greater total water demand does not necessarily result in commensurately greater water stress. To some extent the same reasoning can be applied to the exploration of deeper nutrients by tree species; indeed, where some of the tree material is returned to the soil, as mulch or green manure, for instance, this can provide a beneficial recycling of some nutrients for shallower-rooting crops. But, where the greater productivi[illegible] ntercropping or agroforestry systems results [illegible] ter removal of nutrients, it seems inevitable that, sooner or later, this greater productivity will only be maintainable by higher fertilizer inputs.

These possibilities of greater demands for water and nutrients raise the question of how intercropping systems are likely to perform when water or nutrient supply is severely limited—conditions which commonly occur on the SAT Alfisols. The effects of moisture stress have been studied at ICRISAT over 3 summer seasons by arranging treatments at different distances from a "line source" of closely-spaced irrigation sprinklers. This technique allows a very wide range of moisture situations to be studied on a very small area. Results with a 1:2-row combination of sorghum and groundnut are shown in Figure 3. Under well-watered conditions yields were very high, but with increasing moisture stress they decreased to a level typical of many farms in the

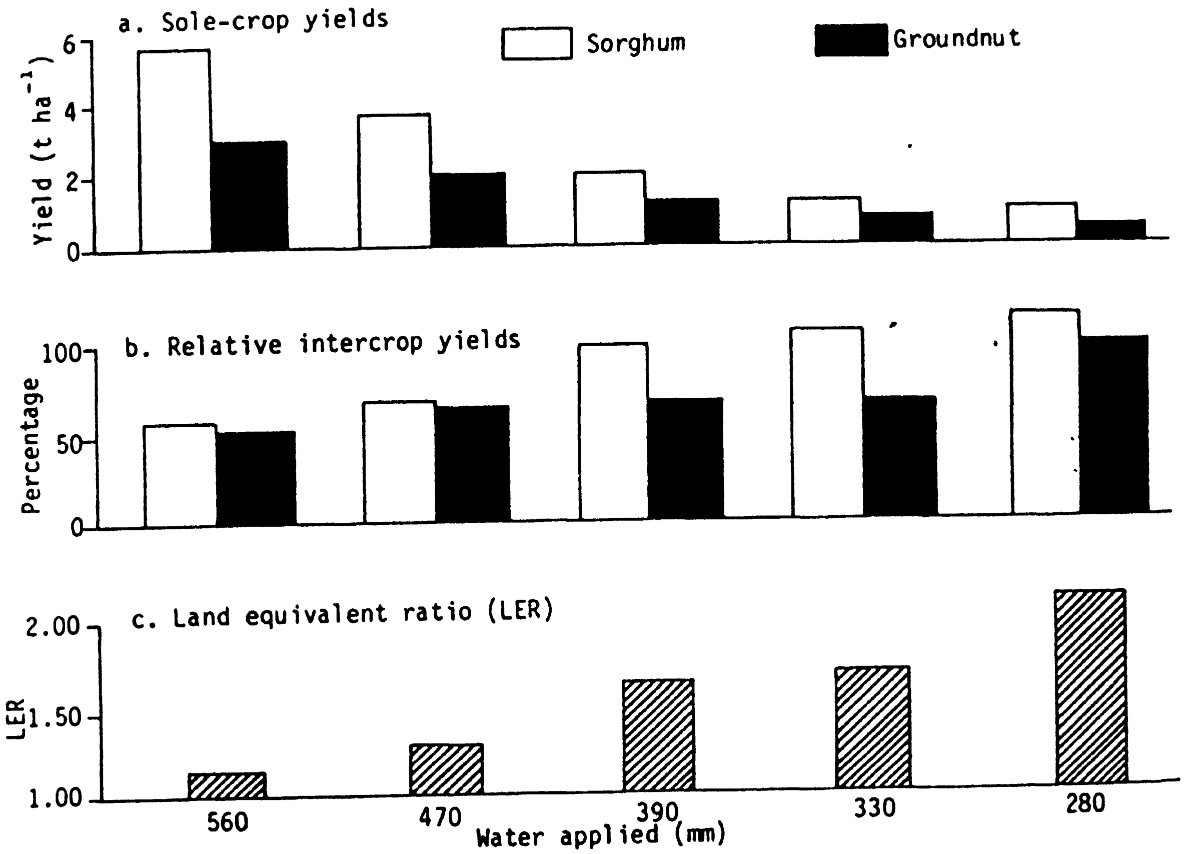

Figure 3. Effects of different moisture regimes on the yield advantages of a 1:2-row sorghum/groundnut intercrop at ICRISAT Center (means of 3 dry seasons: 1980, 1981, and 1982).

dry tropics. But for each crop the relative intercrop yield increased with increasing stress (Fig. 3b), and the overall relative advantage of intercropping thus also increased (Fig. 3c); where stress was greatest, the advantage was a sizeable 109%.

These results suggest that, under drought stress, even though yield levels are low the relative advantages of intercropping are even greater than when the moisture supply is good. However, it should be clear that the systems examined in these ICRISAT experiments were "replacement" systems where the total population of intercrops or sole crops was constant, so that each intercrop component was at a lower population than its sole crop. In such systems, the intercropping advantages can be conveniently explained in terms of complementary resource use, where each crop experiences less competition when growing in combination with the other crop than when growing alone as a sole crop. However, this reasoning is not so acceptable for "additive" systems (as agroforestry systems are likely to be), where additional crop components result in greater total populations and thus, probably, increased competition for water. Clearly, more research is necessary to determine how far the results obtained at ICRISAT with a sorghum/groundnut combination will apply to other systems.

Turning now to nutrient resources, there is similar evidence to show that the relative advantages of intercropping increase with increasing stress, although the effects reported (IRRI 1975, ICRISAT 1981, and Vorasoot 1982) were less marked than those described for drought stress. These results again suggest that intercropping systems may be particularly beneficial under conditions typical of SAT Alfisols, where inherent fertility and fertilizer applications are so often low. It is worth emphasizing, however, that this greater relative importance of intercropping under stress conditions should not be taken to mean that intercropping has no role to play at higher levels of nutrient and/or water availability. It has been pointed out elsewhere (Willey 1979) that, because of higher yields, absolute advantages of intercropping are often more under better conditions.

Legume Benefits

Legumes are common components of intercropping systems and it has often been assumed that they provide some nitrogen benefit. But showing benefits in the field has proved notoriously difficult, not least because nitrogen effects have so often been confounded by other intercropping effects. Nevertheless, there have been instances where a legume appears to have provided either a current benefit to a nonlegume growing in association (CIAT 1974, IARI 1976, Wein and Nangju 1976, and Eaglesham et al. 1981), or a residual benefit to a subsequent crop (Agboola and Fayemi 1972, Searle et al. 1981, and Yadav 1981).

Experiments at ICRISAT with maize/groundnut, sorghum/cowpea, and sorghum/pigeonpea intercrops have been undertaken to attempt to quantify these effects. In general there has been little evidence to show that there is much transfer of N to nonlegume crops actually growing with the legumes. In fact, under low levels of N, when growth of the nonlegumes is poor, the addition of legumes to the system has often resulted in a decrease in the nonlegume yield. But there is evidence of residual benefits on subsequent crops, especially after intercropped groundnut when the benefits were found to be equivalent to 15-20 kg ha^{-1} of applied N.

Some useful general findings have emerged from these experiments. The first is that the nitrogen contribution from many intercropped legumes in conventional intercropping combinations is necessarily very limited because the legumes are only partial crops in the system. Moreover, being usually grain legumes, much of the fixed N is removed in the seed. It is in this context that agroforestry systems may have much to offer: the incorporation of legume tree species may enable much larger qualities of material to be returned to the soil. Another finding of the ICRISAT experiments is that fixation rates may be reduced by shading, even when normal dry-matter growth is unaffected (Nambiar et al. 1983). This is unlikely to be important for the tree species themselves, except in the very early stages of establishment, but shading from the tree species could reduce the legume contribution from conventional crops in the system.

Pests and Diseases

At present there is considerable interest in the possibility that judicious manipulation of cropping systems may improve control over pests or diseases. In the developing areas of the world, in particular, there is obviously considerable merit in any control measure that does not have to depend on chemicals, which can be both costly and difficult to put into practice. Again, it is intercropping systems that seem to have the most to offer.

The commonest effect seems to be where one component crop in the intercropping system acts as a buffer or barrier against the spread of a pest or disease of another component crop. Some standard examples are the use of cereal intercrops to reduce insect attack on cowpeas and the insect-borne rosette disease of groundnut in Africa and bud necrosis disease of groundnut in India. It seems likely that intervening rows of tree species could have similar, or even greater effects; thus agroforestry systems could potentially be very important in this respect. More complex interaction can also occur; research at ICRISAT, for example, suggests that a sorghum intercrop reduces the soil-borne pigeonpea wilt disease by a more active interaction than a simple barrier effect, perhaps a root exudate. Obviously such interactions could also occur in agroforestry systems but, as in intercropping, they are likely to be specific to given crop combinations that will have to be identified. (In the case of pigeonpea wilt, for example, maize did not produce the same effect.) A further factor that should not be forgotten is that adverse as well as beneficial interactions can occur. The sorghum/pigeonpea intercrop serves as an example again (Bhatnagar and Davies 1981). In this combination *Heliothis* sp is a serious insect pest of both crops. It first builds up as a headworm on sorghum but is partially kept under control by some hymenopteran egg parasites. After the sorghum is harvested, the *Heliothis* sp transfers to the pigeonpea as a pod borer, but the hymenopteran parasites do not. The natural parasites on pigeonpea are mainly dipteran larval parasites that are less effective. The net effect of this build-up of the pest on sorghum and lack of transfer of effective parasites is that pigeonpea can suffer greater pod-borer damage as an intercop than as a sole crop. Agroforestry systems will usually be even more complex ecologically than systems with conventional crops and, clearly, similar adverse interactions are possible.

Yield Stability

Another advantage claimed for intercropping systems is that they can provide greater yield stability. The suggested mechanisms for this are better control over pests and diseases, greater relative yield advantages under stress conditions (which act as a buffer in bad years), and the compensation that is possible

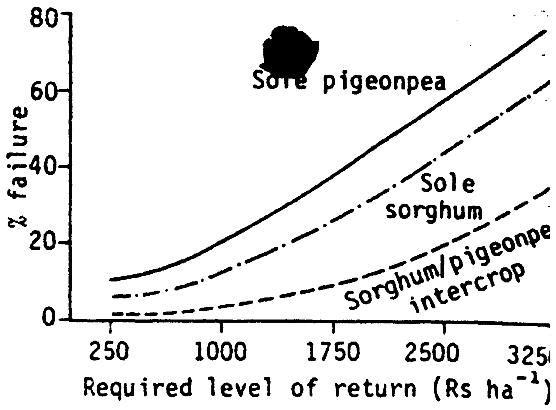

Figure 4. The probability of sole sorghum, sole pigeonpea, or a sorghum/pigeonpea intercrop failing to provide a given level of net monetary return (adapted from Rao and Willey 1980).

from another component crop if one crop fails or grows poorly. A survey of a large number of sorghum/pigeonpea experiments (Rao and Willey 1980) confirmed that, in terms of total monetary returns intercropping "failed" (i.e., produced returns lower than the required level) much less often than comparable sole-crop systems (Fig. 4).

Not forgetting that adverse pest and disease situations may occur, or that systems with higher total populations might worsen environmental stresses, it seems likely that the greater diversity of crops in agroforestry systems could offer even greater overall stability. It is not difficult to imagine, for example, a situation where the conventional crop components might fail because of drought but the tree component would still produce something. This suggests a rather wider concept of stability, however, because any compensatory production from the tree species (e.g., fodder or fuel) is often likely to be very different from the products that have been lost (e.g., basic food crops). This might not matter where marketing is well developed and all products are saleable (and, thus, in theory interchangeable), but this particular kind of compensation may be viewed less advantageously in subsistence situations.

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