Cropping Systems with Groundnut: Resource Use and Productivity

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Abstract

In the rainfed semi-arid tropics (SAT) the relatively short growing season usually limits the choice of cropping systems with groundnut, either to sole-crop or intercropping systems. This paper examines some of the mechanisms associated with environmental factors that can enable intercropping systems to outyield sole-crop systems. Temporal intercropping systems, where the component crops make their peak demands on resources at different times, are illustrated with a groundnut/pigeonpea system. In this system higher yields from intercropping are associated with a fuller use of environmental resources over time. Spatial intercropping systems are illustrated with a 3-year rainy-season study on millet/groundnut. A higher yield from intercropping was most notably associated with improved light-energy conversion. Drought-stress studies on sorghum/groundnut and millet/groundnut showed no stress effects on the relative dry-matter yield advantages of intercropping. However, relative reproductive yield advantages of intercropping increased markedly with stress because the harvest index of sorghum and groundnut decreased much less in intercropping than in sole cropping. The importance of nitrogen fixation in intercropped groundnut and the likely benefits to nonlegume companions or following crops are also discussed.

Résumé

Systèmes de cultures basés sur l'arachide en zones tropicales semi-arides — utilisation des ressources et productivité : *Dans les zones tropicales semi-arides, la durée relativement courte de la période de croissance limite, en agriculture pluviale, le choix de systèmes de cultures de l'arachide, tant en systèmes de culture pure qu'en association. Cette communication porte sur certains mécanismes associés aux facteurs environnementaux, qui permettent aux systèmes de cultures associées de surpasser les systèmes de culture pure. Les systèmes d'association de type temporel, où les membres de l'association ont des besoins maximum de ressources à des périodes différentes, sont illustrés pour l'association arachide/pois d'Angole. Dans ce système, les rendements supérieurs sont dus à une meilleure utilisation des ressources du milieu dans le temps. Les systèmes d'association de type spatial sont illustrés grâce à une étude de trois ans effectuée durant la saison des pluies, sur l'association mil/arachide. L'association a permis d'obtenir de meilleurs rendements grâce, entre autres, à une meilleure conversion de l'énergie. Les études sur le stress hydrique de l'association sorgho/arachide et mil/arachide n'ont montré aucun effet de stress sur les avantages relatifs du rendement en matière sèche de l'association. Cependant, les avantages relatifs de rendement reproductif de l'association ont augmenté sensiblement avec le stress car l'indice de récolte du sorgho et de l'arachide ont beaucoup moins diminué en cultures associées qu'en culture pure. L'importance de la fixation de l'azote par l'arachide associée et les bénéfices probables pour la non légumineuse et les cultures subséquentes sont aussi discutés.*

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an International Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

Introduction

A cropping system growing annual crops is usually defined as the combination of crops grown on a given area within any one year. In humid areas with a potentially long growing period, several cropping systems may be possible. But in rainfed semi-arid areas the possible systems are much more limited. With groundnut, a relatively long-season crop that usually occupies all or at least the greater part of the potential cropping period, there are usually only two alternatives: either the groundnut can be grown as a single sole crop, or it can be interplanted with other crops in an intercropping (or mixed cropping) system.

Despite increasing research attention during recent years, intercropping systems are still poorly understood compared with sole-crop systems, but there is considerable evidence that intercropping can often provide substantial yield advantages over sole cropping. Some of the mechanisms that bring about these advantages are associated with environmental factors. These particular mechanisms and how they operate specifically in groundnut intercropping systems are considered in this paper. Sole-crop systems are considered only where they provide the basis for comparison with intercropping systems.

Use of Environmental Resources

Probably the most common cause of higher yields from intercropping over sole cropping is the improved use of environmental resources. Put very simply, if component crops in an intercropping system use resources differently than when grown together, the crops complement each other and make better overall use of resources than when grown as separate sole crops. For convenience such complementarity is often considered as either temporal or spatial.

Temporal Complementarity

Temporal complementarity occurs when component crops make their major demands on resources at different times during the season. In groundnut systems, this kind of complementarity is particularly evident when groundnut is intercropped with long-season crops such as cotton, castor, pigeonpea, or, in more humid areas, cassava. This kind of combination is common in most groundnut areas, although management of the system may vary considerably according to the relative importance of the component crops. With cotton or castor, which are often regarded as crucial, relatively high-investment cash crops, groundnut is commonly a supplementary crop grown with little or no sacrifice of the cotton or castor. In contrast, groundnut is usually the more important crop in the groundnut/pigeonpea combination commonly grown in India. In this system groundnut is usually sown as a reasonably full stand with only occasional rows or plants of pigeonpea.

Resource use and productivity in these temporal systems is illustrated by some work at ICRISAT Center on a groundnut/pigeonpea combination. Two-row arrangements, in which pigeonpea was grown in rows spaced at 1.2 m and 1.5 m with three and five intervening rows of groundnut respectively, were examined. Within-row spacings were adjusted so that each crop had a plant population equivalent to a full sole crop as an attempt to produce high yields in each. There was little difference between the two treatments so only mean yields are presented here. The groundnut (cv Robut 33-1) was harvested at 95 days after emergence (DAE) and the pigeonpea (cv ICP 1) at 175 DAE.

For most of its growing period the dry-matter accumulation of intercropped groundnut was only about 10-15% less than the full groundnut sole crop (Fig. 1A). At least in the early stages it is unlikely that this yield loss was due to competition from the pigeonpea, which established very slowly, and was probably because compared with sole groundnut, the intercropped groundnut was unable to utilize the space allocated to the pigeonpea. By final harvest, however, yield loss of intercropped groundnut was 24%. By this stage some of this effect may well have been due to pigeonpea competition. Dry-matter accumulation of pigeonpea was much more affected by intercropping. Yield loss for the first 110 d ranged between 40-50%, almost certainly due in part to competition from the groundnut. But in the later stages of its growth the intercropped pigeonpea was able to benefit from the removal of the groundnut and by final harvest the total dry matter was only 28% less than sole pigeonpea. Considering the combined intercropped yield, groundnut produced 76% of a full sole crop and pigeonpea 72%, i.e., there was an overall dry matter-yield advantage of 48%. Harvest indices were slightly higher in intercropping than in sole cropping, so reproductive yields were 80% and 78%, respectively, giving a yield advantage of 58%. This advantage was at a very high level of productivity: the intercrop absolute yields were 3287 kg ha^{-1} of groundnut and 1155 kg ha^{-1} of pigeonpea.

These results are from a single-season experiment, but they typify what is possible with this combination. A set of multilocational stability experiments (5 locations × 4 years) with the same combination gave an average overall advantage of 53%. Other workers have regarded the pigeonpea as a supplementary component: Appadurai and Selvaraj (1974) reported a 37% yield of pigeonpea while still maintaining 99% groundnut yield; John et al. (1943) reported that groundnut/pigeonpea intercropping was 43% more profitable than sole groundnut. In contrast, in other temporal combinations the groundnut has been regarded as the supplementary component. Compared with sole castor, groundnut/castor was 62% more profitable (Reddy et al. 1965) and 32% more profitable (Tarhalkar and Rao 1975). Similarly, Joshi and Joshi (1965) and Varma and Kanke (1969) have shown significant increases in yield and profitability from groundnut/cotton intercropping compared with sole cotton.

The resource-use pattern in these temporal combinations is exemplified by the light interception observed in the ICRISAT groundnut/pigeonpea experiment (Fig. 1B). In the sole crops, the fairly rapidly establishing groundnut reached its maximum interception by about 45-50 d, while the much slower-growing pigeonpea took until 90-100 d. In the intercrops, early interception was as good as sole groundnut, which was obviously due to the presence of a high groundnut population. At groundnut harvest the interception fell to 50-60%, but by virtue of the high pigeonpea population, it stayed at a reasonable level until pigeonpea harvest. In total, therefore, intercropping intercepted more energy throughout the season than either of the sole crops. The conversion efficiency of total intercepted energy into dry matter in intercropping was the same as in sole cropping. Thus the higher total dry matter in intercropping was produced not by more efficient conversion of light, but by greater interception. Although other resources were not examined in this experiment, light, water, and nutrients have all been examined in detail in a temporal combination of a 90-day sorghum with pigeonpea (Natarajan and Willey 1979). For all three resources a large yield increase in an intercrop was due to the utilization of more resources, and not more efficient conversion into dry matter. Generally in an intercrop combination where there is a large temporal difference between the components, the simple effect is that the more rapidly growing crop ensures good use of early resources, and the slower-growing crop ensures good use of later resources. Higher yields are thus produced by the simple process of more complete resource utilization over time.

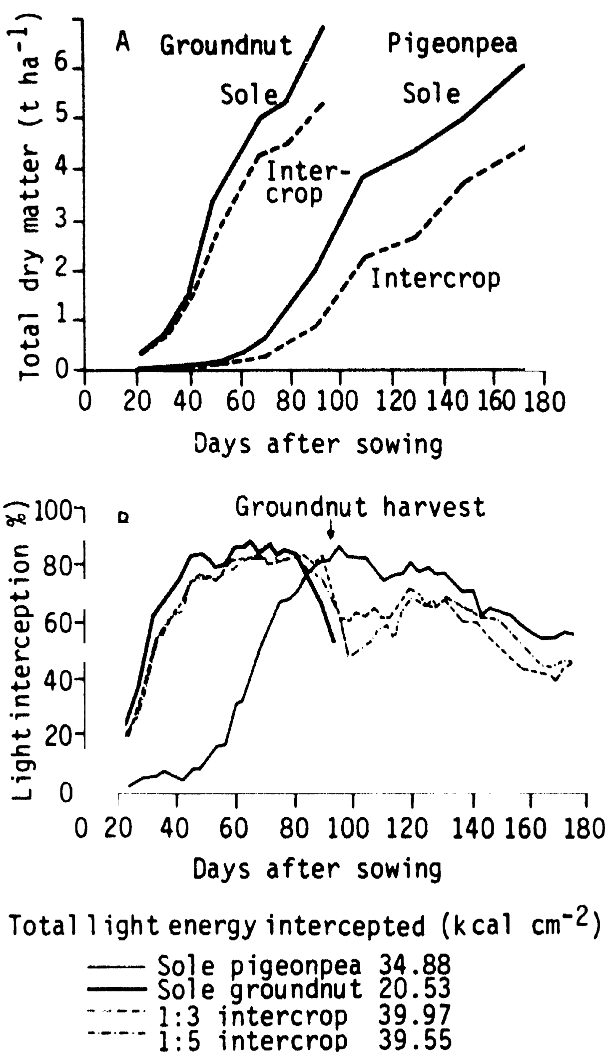

Figure 1. Dry-matter accumulation and light interception in groundnut/pigeonpea intercrop.

Spatial Complementarity

The commonest groundnut intercrop is with a cereal. In semi-arid areas, where the cereal is normally sorghum or pearl millet, the short growing season often means that there is little difference between the maturity periods of component crops and thus much less scope for the kind of temporal complementarity discussed in the previous section. Productivity and resource use in these cereal/groundnut systems is illustrated by some ICRISAT studies on a pearl millet/groundnut combination (Willey et al. 1983). Figure 2A shows a 3-year average for a

1-row millet/3-row groundnut combination in which within-row spacing for each component was the same as in sole crops. Plant populations were therefore the same as row proportions, i.e., 25%:75%. This arrangement is typical of systems where groundnut is the major crop, with several rows of groundnuts interspersed between only occasional rows of cereal. The millet was BK 560, harvested at 85 d, and the groundnut was Robut 33-1, harvested at 100 d. For most of the growing period the groundnut

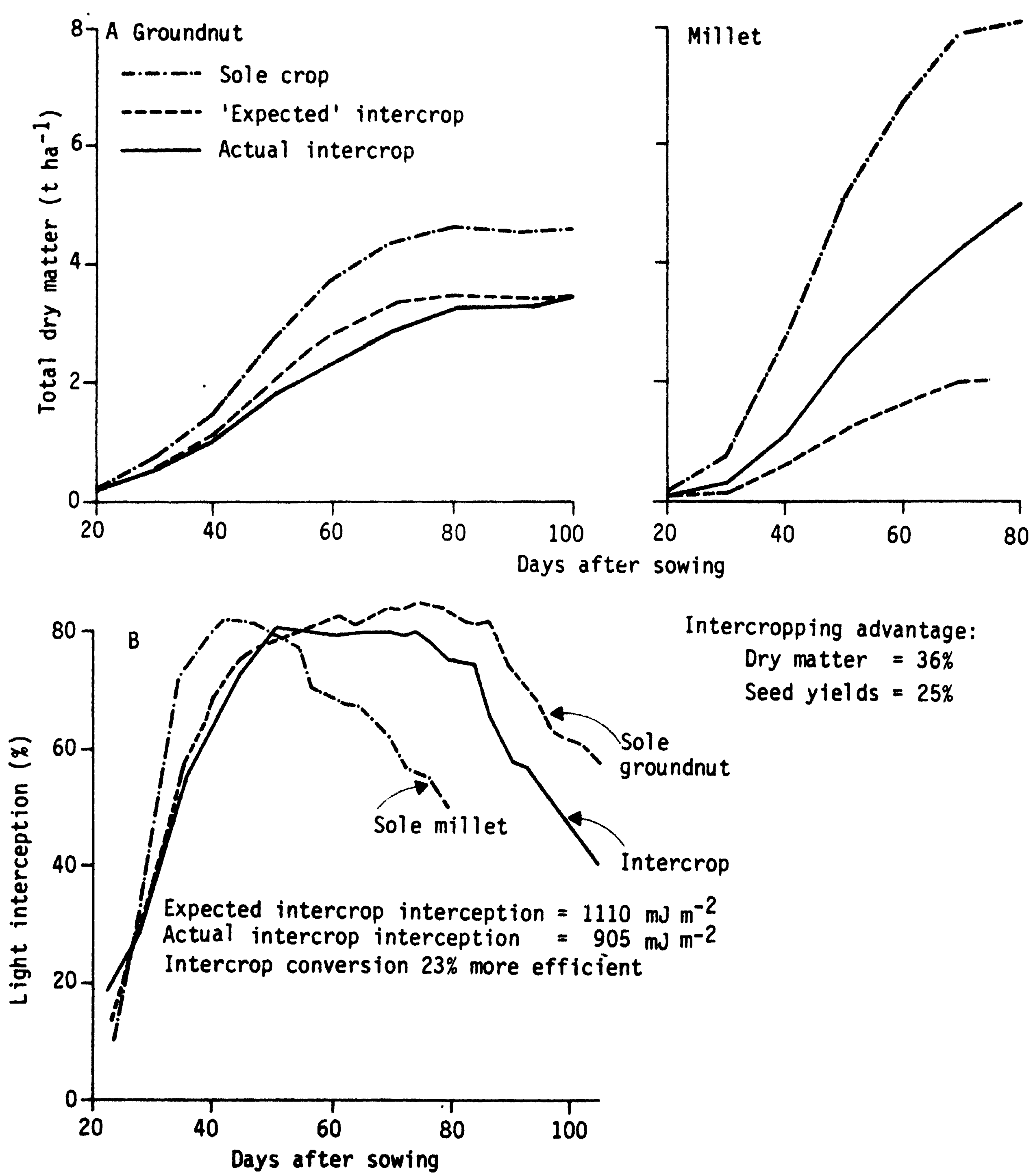

Figure 2. Dry-matter accumulation and light interception in pearl millet and groundnut as sole crops and as a 1-row millet: 3-row groundnut intercrop (means of 1978, 1979, and 1980).

Accumulation of dry matter was a little less than the 75% sole-crop yield expected from the sown proportion in intercropping; thus groundnut growth was to some extent suppressed by the presence of millet. Towards the end of the season, however, when millet was senescing and was eventually harvested, the groundnut was able to recover, and its final yield was equivalent to that expected. In effect, final yield per plant was the same in intercropping as in sole cropping. In contrast, dry-matter accumulation of the millet, the more competitive crop, was more than twice its 25% sole crop expected level, and at final harvest the yield was 62% of the sole crop. Combining these dry matter yields gave an overall advantage for intercropping of 36%. For reproductive yields the advantage was a little lower (25%) because of small decreases in the harvest indices of both crops. These results are reasonably consistent with other studies that have shown intercropping advantages of up to 57% with sorghum (Evans 1960, Rao and Willey 1980, Tarhalkar and Rao 1975), and up to 54% with maize (Evans 1960, Koli 1975).

Light interception in this intercropping combination showed a pattern intermediate between the two sole crops (Fig. 2B), but intercepted energy was converted into dry matter 23% more efficiently than in sole crops. Thus, in contrast to the groundnut/pigeonpea combination, the higher yield in the intercrop was only partly due to the interception of more light, but mainly due to more efficient light conversion. In effect, therefore, this combination must have displayed some spatial complementarity between the component canopies so that overall conversion efficiency was increased. One obvious possibility is that the erect C4 millet leaves made efficient use of the high light intensities at the top of the canopy while the compact C3 groundnut canopy made efficient use of the lower light intensities in the bottom of the canopy. A detailed study that tried to separate the light use of the two crops showed that on a plant-for-plant basis, intercropped groundnut intercepted 27% less light than the sole crop, but yielded the same. It seems likely, therefore, that one of the major mechanisms in this particular situation was that shading by millet improved overall light-use efficiency (LUE) by reducing light saturation in the groundnut.

Examination of water use in these millet/groundnut experiments was not very conclusive, perhaps partly because the experiments were conducted in good rainy seasons when there was little drought stress. However, there were indications that the increased yields in the intercrop were partly because of a greater total water use, and partly because of reduced evaporation losses. The nutrient-use pattern was quite clear however, and was similar to the groundnut/pigeonpea combination in that higher yields in intercropping were associated with commensurately higher nutrient uptake. The implication of this greater nutrient uptake may be that higher intercropping yields will have to be paid for with higher fertilizer inputs. But there is the possibility that complementarity between intercrop components, perhaps because of different rooting patterns, could allow the uptake of some nutrient resources that would not otherwise be used.

Effects of Environmental Stress

These millet/groundnut studies were carried out under good conditions: the rainfall was adequate and the millet component received nitrogen equivalent to 80 kg ha^{-1} for a sole crop. Further studies examined how the relative advantages of intercropping were affected by limited supplies of water and/or nutrients, two factors of crucial importance in the rainfed SAT. These studies were also designed to determine if the importance of improved light-energy conversion observed in the earlier experiments was at least partly because other resources were not limiting. A dry-season experiment (Vorasoot 1982) on the same millet/groundnut system examined treatments of low drought stress (irrigated every 10 d) and drought stress (irrigated every 20 d) factorially combined with low nitrogen stress (80 kg N ha^{-1}) and nitrogen stress (0 kg N ha^{-1}). Table 1 indicates that compared to having a good supply of both resources, the relative yield advantage of intercropping increased slightly if there was lack of either water or nitrogen, and it increased even further if there was no evidence that improved efficiency of light-energy conversion became less important as below-ground resources became more limiting. Similarly there was no evidence that an improved water-use efficiency (WUE) was affected by the degree of drought or nitrogen stress.

One of the problems with this stress experiment, which was laid out in a conventional design, was the inability to examine a reasonable number and range of moisture regimes. Two subsequent experiments examined a range of five moisture regimes by establishing treatments at different distances from a line-source system of irrigation sprinklers. The whole experimental area was uniformly irrigated up to 25 DAE, and thereafter uniform irrigations were given

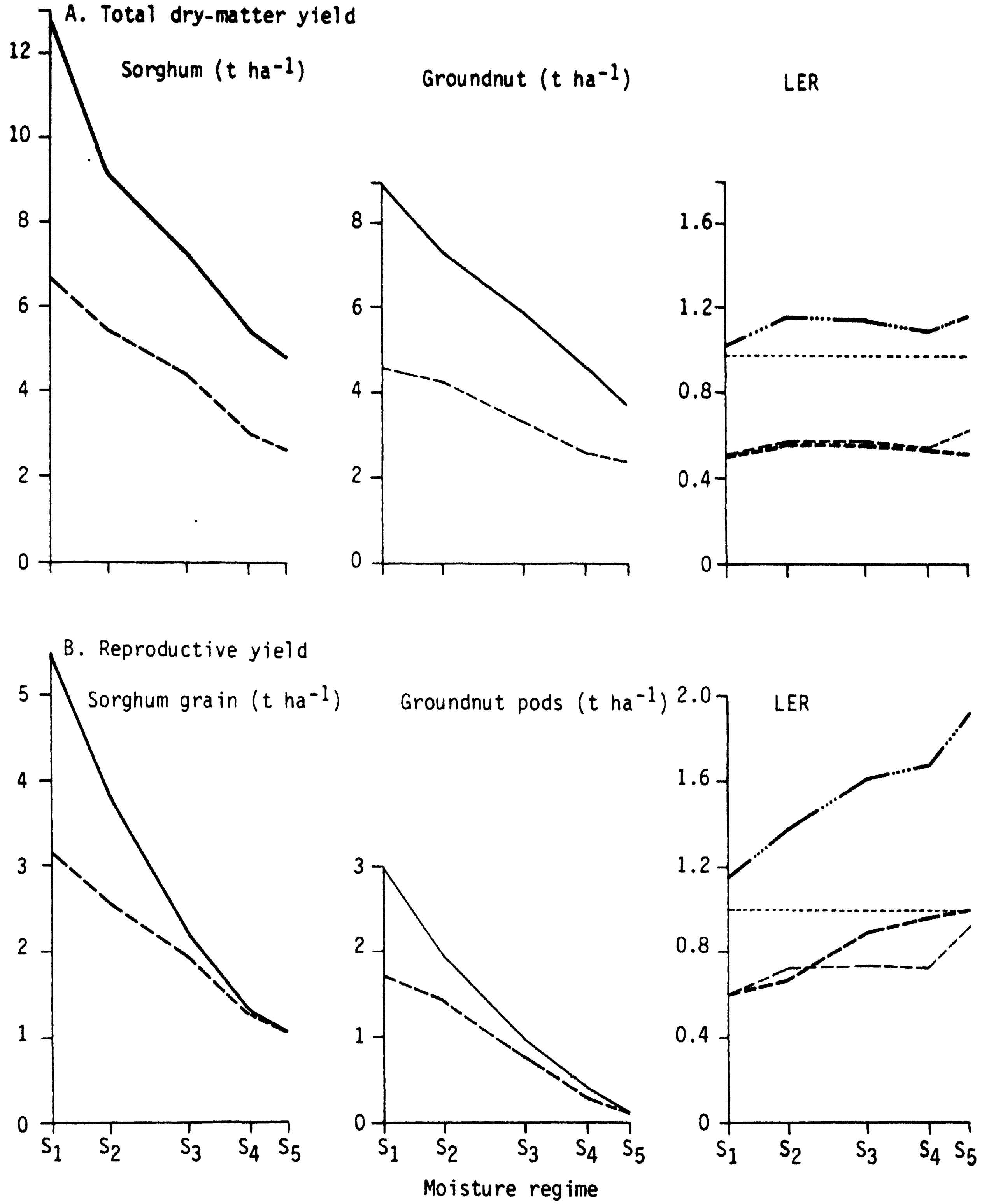

Figure 3. Effect of moisture regime on yields and LERs of a 1-row sorghum:2-row groundnut intercrop (SGG).

——Sole sorghum, – – – –intercrop sorghum, —— sole groundnut,

– – – –intercrop groundnut, —·—total LER.

Table 1. Effects of drought and/or nitrogen stress on yield advantages and efficiency of resource use in a millet/groundnut intercrop compared with sole crops.

	No stress	N stress only	Drought stress only	Drought stress and N stress
LER[1]	1.21	1.27	1.29	1.39
Increase in LCE[2] (%)	+16	+33	+27	+24
Increase in WUE[3] (%)	+14	+23	+31	+24

1. LER = Land-Equivalent Ratio (e.g. a value of 1.21 represents an intercropping yield advantage of 21%).
2. LCE = Light-Conversion Efficiency (based on intercepted light).
3. WUE = Water-Use Efficiency (based on transpired water). Source: Vorasoot 1982.

at 55 and 85 d. Moisture gradients were imposed with line source irrigations at 35, 45, 65, 76, and 95 d. Averaged over the two experiments, actual water received through uniform irrigations and rainfall was 286 mm. Water application through the line source ranged from 298 mm at the well-watered end (S1) to only 11 mm at the stress end (S5). Thus total water received ranged from 584 to 297 mm, which was equivalent to 64-33% of open-pan evaporation.

Three combinations were studied (Natarajan and Willey, in press) but only some sorghum/groundnut and millet/groundnut treatments are presented here. There were two intercropping treatments with each cereal: 1-row sorghum or millet/2-row groundnut (SGG or MGG), and 1-row sorghum or millet/3-row groundnut (SGGG or MGGG). Results are presented as means of the two experiments. In the sorghum/groundnut combination, Figures 3 and 4 show that total dry-matter yields of the sole crop were markedly affected in both crops, ranging from very high yields at S1 to very low yields at S5. Reproductive yields were even more drastically reduced by increased drought stress because of large decreases in harvest indices; sorghum harvest index decreased from 43% at S1 to 20% at S5, while the comparable groundnut decrease was from 34% to only 3%.

Considering the SGG intercrop (Fig. 3), the total dry-matter yield of each component remained a fairly constant proportion of its sole-crop yield over the whole range of moisture regimes. Thus the intercropped dry matter advantage also remained fairly constant at about 10-20% . However, with stress increase, the harvest index of each component decreased less in the intercrop than in the sole crop particularly for the sorghum, so reproductive yields in the intercrop were equivalent to an increasing proportion of sole-crop yields. Consequently the intercropped advantage for reproductive yields increased from 14% at S1 to 93% at S5. The SGGG treatment showed a similar trend as stress increased from S1 to S3, but the maximum intercropped advantage was only 37% (at S3), and this declined under greater stress. This declining advantage in the severest stress treatments was particularly associated with a decrease in the groundnut contribution. In the millet systems (Figs. 5 and 6), the harvest index of sole millet was only slightly reduced with increased stress, and there was no evidence of any change in the intercropped millet yield relative to sole-crop yield. There was again evidence of greater relative advantages of the intercrop with increase in stress, but this was entirely due to an increase in the groundnut contribution, again attributable to a change in harvest index. In the MGGG treatment the maximum relative advantage of 78% was at S4, in MGGG there was an initial increase of up to 34% at S2 but a decline at higher stress levels.

No measurement of resource use was possible in these experiments, so the possible mechanisms responsible for different magnitudes of yield advantage with different degrees of stress can only be commented on generally. A commonly suggested advantage of intercropping is that crops may complement each other by rooting at different depths, and if this utilizes water more fully, it can be argued that this effect would be most advantageous when moisture is most limiting. There is also some indication that the presence of a shallow-root component may force a deep-root component even deeper (Natarajan and Willey 1981). The rather surprising feature of these results, however, is that increased stress did not affect total dry matter advantages of intercropping but only the reproductive yield advantages. But this could have occurred because all treatments were well watered initially, and stress only built up later in the

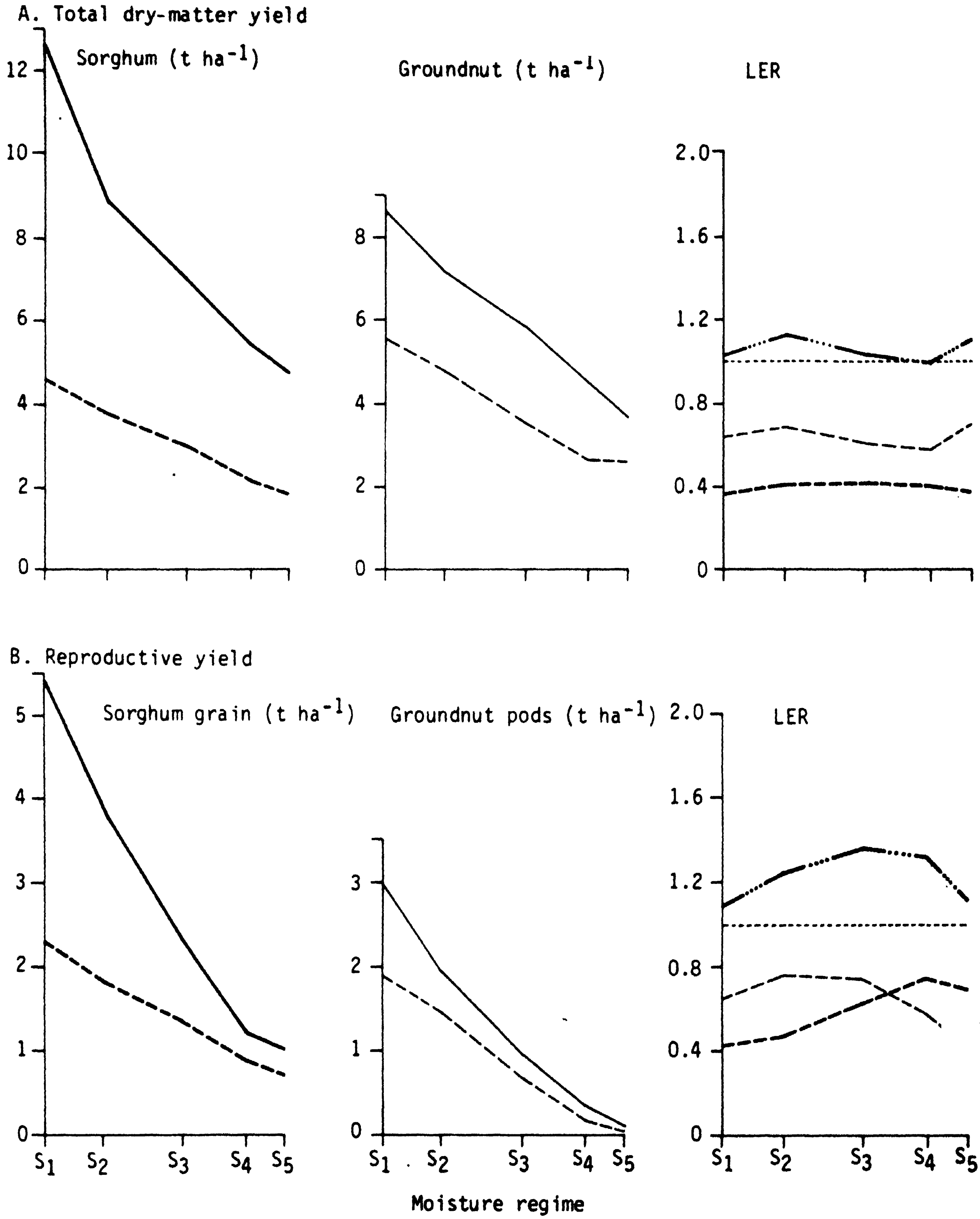

Figure 4. Effect of moisture regime on yields and LERs of a 1-row sorghum:3-row groundnut intercrop (SGGG).

—— sole sorghum, - - - - intercrop sorghum, —— sole groundnut, - - - - intercrop groundnut, —·—·— total LER.

season when reproductive yields were being formed. This could also explain why the millet, which matured much earlier than the other crops, did not contribute to this effect.

A further possible mechanism is that the cereals provided a beneficial shading effect on the groundnut. This mechanism could help to explain the lower advantages in the SGGG and MGGG treatments, because in these treatments the shading effect was presumably less. It could also perhaps explain the drop in groundnut contribution and in reproductive yield advantage in the severest stress treatments for

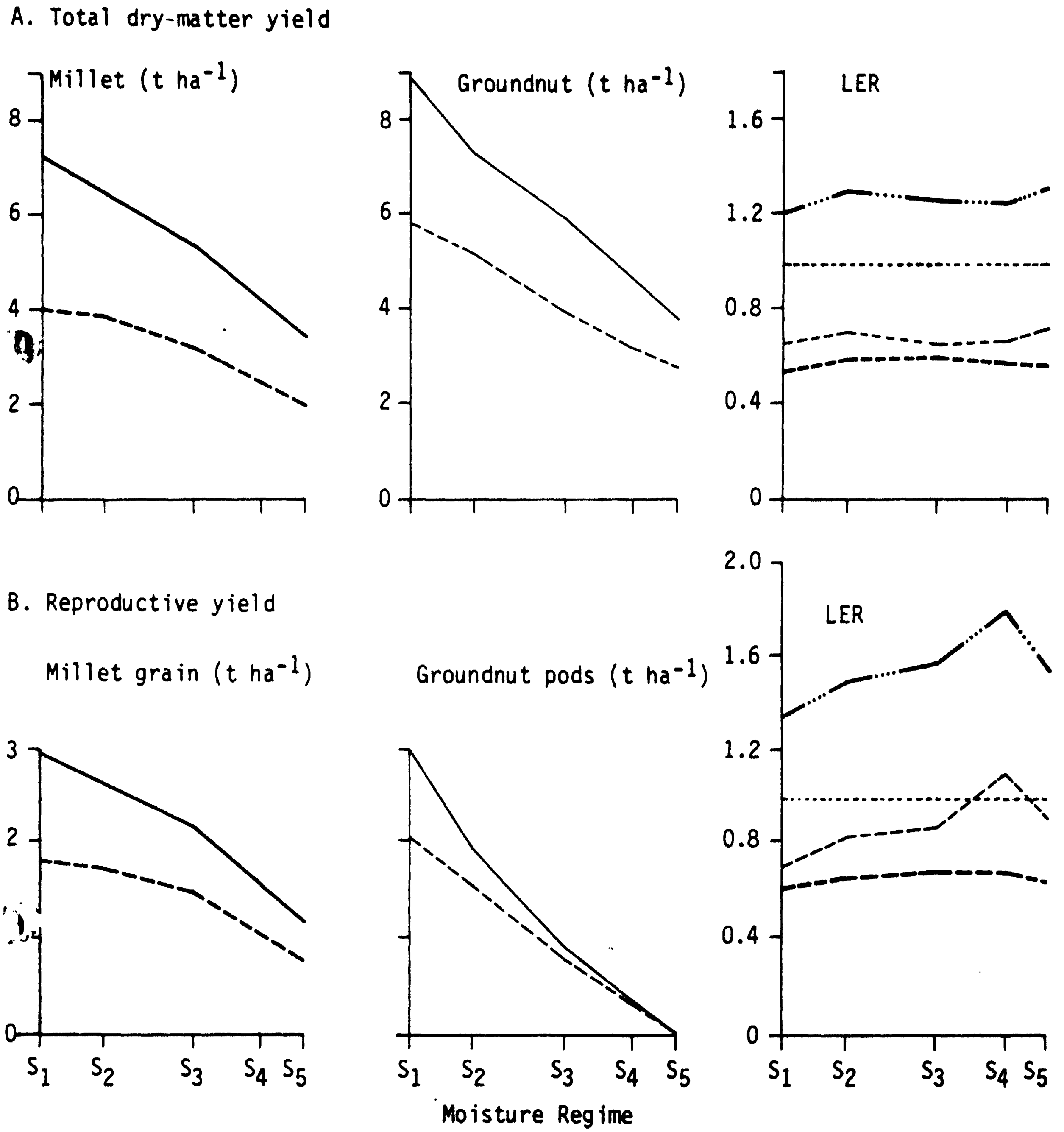

Figure 5. Effect of moisture regime on yields and LERs of a 1-row millet:2-row groundnut intercrop (MGG).

——— sole millet, — — — intercrop millet, ——— sole groundnut, - - - - - intercrop groundnut, —·—·— total LER.

SGGG and MGGG because it was in these situations that general crop growth was poorest, and thus shading was at a minimum. More recent studies (D. Harris, University of Nottingham, UK, personal communication) have supported this possibility of a beneficial shading mechanism by showing lower leaf temperatures in intercropped groundnut than in sole groundnut. But of course this mechanism cannot explain why the sorghum crop also had a higher harvest index in intercropping than in sole cropping, and if anything, this component made a somewhat greater contribution than the groundnut to the large yield advantage under stress.

The implications of these results are that although there is good evidence of some very large intercropping advantages under conditions of drought stress, these advantages may be specific to particular systems in terms of the crops they involve, and the plant populations and row arrangements at which they are grown. It must be emphasized that in the studies

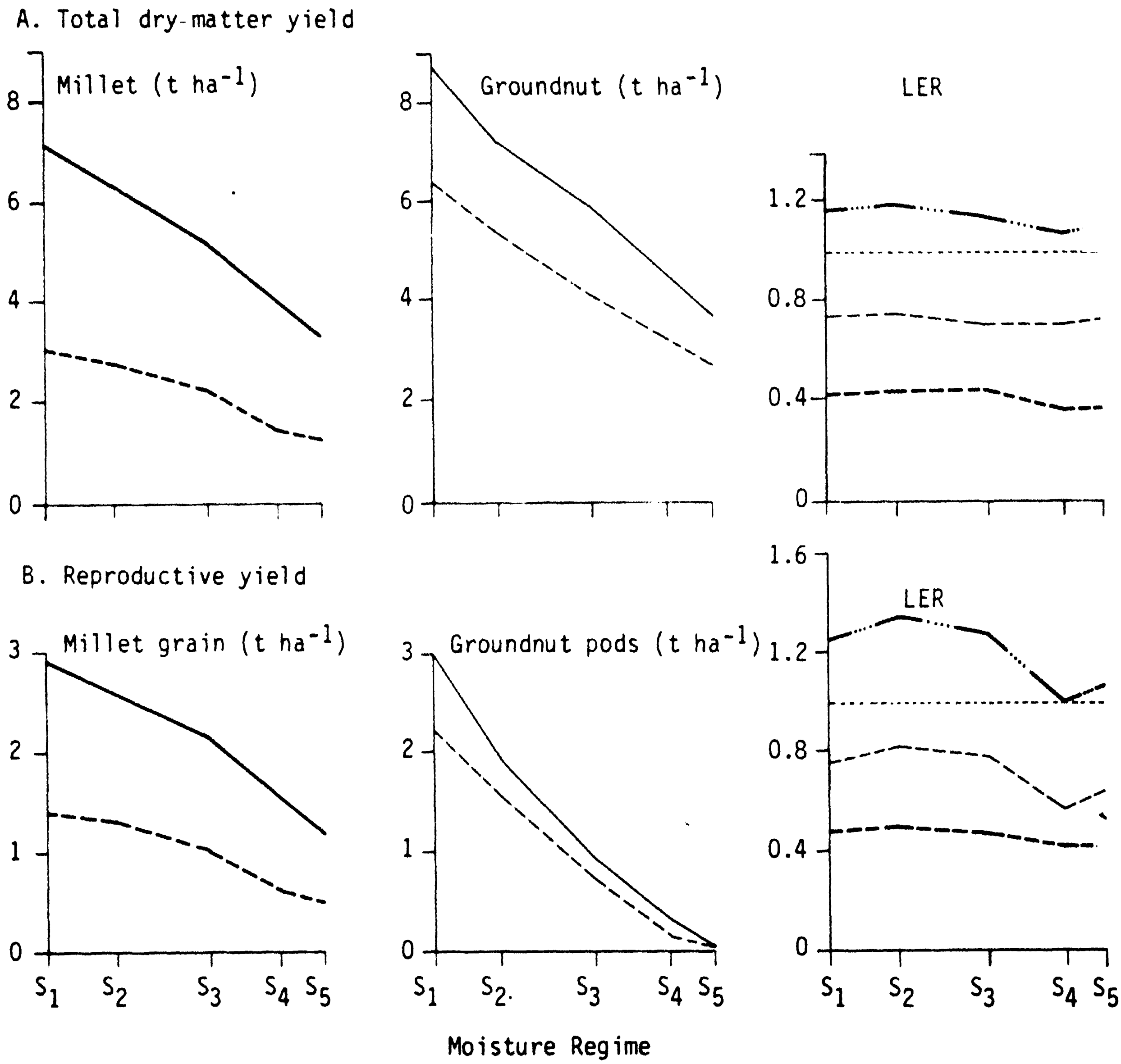

Figure 6. Effect of moisture regime on yields and LERs of a 1-row millet:3-row groundnut intercrop (MGGG).

——— sole millet, – – – –intercrop millet, ——— sole groundnut,
- - - - - intercrop groundnut, —···—total LER.

reported here, total intercrop populations were equivalent to the sole crops, and the population of each individual component was therefore only a proportion of its sole crop. In this situation there is scope for some complementarity between the crops, with a given component experiencing less competition in intercropping than in sole cropping. However, if total plant populations are greater in intercropping than in sole cropping then increased drought stress could lower yields. For example, Fisher (1977) suggested that intercropping was advantageous when the moisture supply was good but not when it was limited, but this was concluded from a maize/bean combination in which total intercrop population was higher than the sole crops.

Symbiotic Nitrogen Fixation

One of the advantages frequently claimed for intercropping combinations which include a legume is that the nitrogen economy of the system is improved because of symbiotic fixation. But there is little practical evidence for this because nitrogen effects are very often confounded with other competitive or complementary interactions between the crops. Also, fixation has seldom been measured directly, but has usually been inferred from yield responses. However, research has produced some guidelines that can help assess likely benefits.

Considering first of all the total amount of nitrogen that an intercropped legume might return to the soil, it must be remembered that as with sole crops, this depends very largely on how much of the plant is removed from the field at harvest. The removal of the seed takes off a large amount of plant nitrogen, and in the case of groundnuts the haulm is also sometimes removed for animal feed. It must also be emphasized that intercropped legumes are almost invariably partial crops and so cannot be expected to [illegible] or leave in the soil, as much nitrogen as a full sole crop. A further factor is that nitrogen fertilizer may well be applied to the nonlegume and it is commonly suggested that this may decrease fixation. In fact ^{15}N studies have shown that virtually no fertilizer nitrogen was taken up by a groundnut row growing only 30 cm away from a millet row to which a high level of fertilizer was applied. This was attributed to the much greater competitive ability of the millet to forage for soil nitrogen (ICRISAT 1984). However, there is considerable evidence that nitrogen application can increase growth, and the competitive ability of a nonlegume can reduce growth and presumably the amount of fixation of a legume component. An important point here is that the rate of fixation might be even more susceptible than general growth to this kind of competition. Some ICRISAT studies with maize/groundnut showed that with an increase in the amount of applied nitrogen to the maize, the number and weight of nodules per groundnut plant decreased more rapidly than the dry-matter yield per plant. Similarly, in one of the rainy-season millet/groundnut studies referred to earlier, the amount of fixation per groundnut plant (measured directly by acetylene reduction) was considerably less in the intercrop than in the sole crop even though dry-matter yield per plant was virtually unaffected (Nambiar et al. 1983). The most obvious cause of this decreased nodulation and fixation was lower light-energy receipts by the groundnut because of shading by the cereals, an effect that was measured in both studies. The important implication, however, is that shaded groundnut intercrops may well be fixing even less nitrogen than might be supposed from their growth.

There remains the question of how any fixed nitrogen might benefit the overall intercropping system. It is most commonly supposed that the benefit is a direct one to any nonlegume crop actually growing with the legume. But the benefit can also occur as a residual effect on subsequent crops. Studies with a range of legumes have indicated that a direct benefit is most likely to occur when the legume is the earlier maturity component and thus releases some nitrogen sufficiently early for an associated nonlegume to be able to respond. Conversely, when the legume is later-maturing, any benefit is more likely to be expressed as a residual one on following crops (Agboola and Fayemi 1972, Nair et al. 1979). Thus groundnut seems most likely to provide a direct benefit only to the kind of long-season intercrop described earlier. For example, there are reports of benefits to castor and cassava intercrop (Reddy et al. 1965, Khon Kaen University 1977). But if groundnut is intercropped with cereals, any benefit is more likely to be on following crops. This residual effect, and some of the other effects discussed above, are illustrated by a 3-year maize/groundnut study at ICRISAT Center. Sole maize was grown as two rows 75 cm apart on a 150-cm bed. This same pattern was maintained in intercropping to avoid confounding spatial arrangement or plant population effects with intercropping effects. The groundnut was added as two intervening rows. Residual effects were examined on a following sorghum crop to which four levels of nitrogen were applied to allow any benefit to be quantified in terms of an equivalent amount of applied nitrogen.

With no nitrogen added the sole maize crop was relatively poor (2.19 t ha^{-1}). Adding a groundnut intercrop gave a good yield of groundnut (1.17 t ha^{-1}) in this low-nitrogen situation, but far from giving any evidence of nitrogen transfer, there was a net competitive effect by groundnut, and maize yield was reduced by 23%. However, this good groundnut intercrop provided a benefit to the following sorghum that was estimated to be equivalent to about 20 kg ha^{-1} of applied nitrogen. When nitrogen was added to the maize the yields of maize were good but groundnut was very much suppressed (0.46 t ha^{-1}). Emphasizing an earlier point, there was no evidence that this poor groundnut intercrop provided any benefit either to the maize or to the following sorghum.

Despite the lack of evidence for direct benefit to a companion nonlegume, there may still be important indirect nitrogen benefits because of the presence of a groundnut intercrop. In systems where the nonlegume intercrop is grown at a lower plant population than a sole crop, there may be a nitrogen benefit because, as emphasized earlier (ICRISAT 1984), the groundnut is less competitive for soil nitrogen. In effect, this means that the nonlegume intercrop may be able to obtain more nitrogen per plant than as a sole crop. This possibility is supported by a millet/groundnut study in which the intermingling of millet and groundnut root systems was prevented by inserting underground partitions between the crop rows (Willey and Reddy 1981). Intercropped millet growing between partitions was paler, and presumably short of nitrogen, compared with an unpartitioned intercrop. In the unpartitioned systems millet was able to take up nitrogen from the rows examined by groundnut, confirmed more recently with ^{15}N studies (ICRISAT 1984). Thus it seems possible that a groundnut intercrop may still indirectly improve the nitrogen status of a nonlegume companion crop, even where it does not make any fixed nitrogen available. This effect could be particularly important in the many semi-arid areas where soil nitrogen is extremely low.

References

Agboola, A.A., and **Fayemi, A.A.A.** 1972. Fixation and excretion of nitrogen by tropical legumes. Agronomy Journal 64:409-412.

Appadurai, R., and **Selvaraj, K.V.** 1974. A note groundnut-redgram mixture in lower Bhawani Proj area. Madras Agricultural Journal 61:803-804.

Evans, A.C. 1960. Studies of intercropping. 1. Maize or sorghum with groundnuts. East African Agricultural and Forestry Journal 26:1-10.

Fisher, N.M. 1977. Studies in mixed cropping. 1. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenya highlands. Experimental Agriculture 13:177-184.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1984. Annual report 1983. Patancheru, A.P. 502 324, India: ICRISAT.

John, C.M., Seshadri, C.R., and **Rao, M.B.S.** 1943. Mixed cropping of groundnut. Madras Agricultural Journal 31:191-200.

Joshi, S.N., and **Joshi, H.V.** 1965. Mixed cropping of groundnut/cotton under irrigated conditions in Saurashtra. Indian Oilseeds Journal 9(4):244-248.

Khon Kaen University. 1977. Khon Kaen/Ford Foundation Cropping Systems project annual report. Pages 25-39 *in* Intercropping of cassava with field crops. Khon Kaen, Thailand: Khon Kaen University.

Koli, S.E. 1975. Pure cropping and mixed cropping of maize and groundnuts in Ghana. Ghana Journal of Agricultural Science 8:23-30.

Nair, K.P.P., Patel, V.K., Singh, R.P., and **Kaushik, M.K.** 1979. Evaluation of legume intercropping in conservation of fertilizer nitrogen in maize culture. Journal of Agricultural Science (UK) 93:183-194.

Nambiar, P.T.C., Rao, M.R., Reddy, M.S., Floyd, C.N., Dart, P.J., and **Willey, R.W.** 1983. Effect of intercropping on nodulation and N_2-fixation by groundnut. Experimental Agriculture 19:79-86.

Natarajan, M., and **Willey, R.W.** 1981. Sorghum-pigeonpea intercropping and the effects of plant population density. 2. Resource use. Journal of Agricultural Science (UK) 95:59-65

Natarajan, M., and **Willey, R.W.** (In press.) The effects of water stress on yield advantages of intercropping systems. Field Crops Research.

Rao, M.R., and **Willey, R.W.** 1980. Preliminary studies of intercropping combinations based on pigeonpea or sorghum. Experimental Agriculture 16:29-39.

Reddy, G.P., Rao, S.C., and **Reddy, R.** 1965. Mixed cropping in castor. Indian Oilseeds Journal 9(4):310-316.

Reddy, M.S., and **Willey, R.W.** 1981. Growth and resource use studies in an intercrop of pearl millet/groundnut. Field Crops Research 4:13-21.

Tarhalkar, P.P., and **Rao, N.G.P.** 1975. Changing concepts and practices of cropping systems. Indian Farming 25(3):3-7, 15.

Varma, M.P., and **Kanke, M.S.S.** 1969. Selection of intercrops for cotton in India. Experimental Agriculture 5:223-230.

Vorasoot, N. 1982. A biological study of the benefit of intercropping in England and India. Ph.D. thesis, University of Reading, Reading, UK.

Willey, R.W., and **Reddy, M.S.** 1981. A field technique for separating above- and below-ground interactions in intercropping: an experiment with pearl millet/groundnut. Experimental Agriculture 17:257-264.

Willey, R.W., **Natarajan, M.**, **Reddy, M.S.**, **Rao, M.R.**, **Nambiar, P.T.C.**, **Kannaiyan, J.**, and **Bhatnagar, V.S.** 1983. Intercropping studies with annual crops. Pages 83-100 *in* Better Crops for Food, Ciba Foundation Symposium 97, 14-16 Sep 1982. London, UK: Pitman.