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THE EFFECTS OF WATER STRESS ON YIELD ADVANTAGES OF INTERCROPPING SYSTEMS

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ABSTRACT

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Two experiments are reported in which a line-source irrigation system was used to study the effects of a range of moisture regimes (S1 to S5 in order of increasing stress due to insufficiency of moisture) on sole crops of sorghum, millet and groundnut, and intercrops of 1 row sorghum : 2 rows groundnut (SGG), 1 row sorghum : 3 rows groundnut (SGGG), 1 row millet : 1 row groundnut (MG), 1 row millet : 2 rows groundnut (MGG), 1 row millet : 3 rows groundnut (MGGG), and 1 row sorghum : 1 row millet (SM). The dry matter yield advantages of intercropping compared with sole cropping ranged from 8 to 30% for the millet/groundnut systems, 0 to 19% for the sorghum/groundnut systems and 5 to 15% for the sorghum/millet system; moisture stress had no consistent effect on these dry matter advantages. For reproductive yields, all the intercropping systems showed some increase in relative advantages with increase in stress because of higher harvest indices in intercropping than in sole cropping. Largest advantages were 93% for SGG at S5 moisture regime and 78% for MGG at S4 moisture regime, both of these being significantly greater than advantages at S1. The level of stress giving peak advantages depended on crop combination and crop proportions.

It is emphasised that all intercropping treatments were of 'replacement' type in which the plant population of each crop was only a proportion of that of its sole crop and total population was equivalent to that in either of the sole crops. It is suggested that if total populations in the intercrops are higher than in the sole crops then, under stress conditions, intercropping yields could well be less than sole crop yields because of increased competition for moisture.

INTRODUCTION

Intercropping is a common traditional practice throughout the tropics, and recent work has shown that it can give higher yields than sole cropping (Willey, 1979). One of the reasons put forward for these higher yields is that the component crops complement each other and make better overall use of resources when growing together than when growing separately.

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Earlier studies at ICRISAT have shown that this better use of resources may occur as a fuller use of resources over time (Natarajan and Willey, 1980), or to some extent as a more efficient use of resources in space (Reddy and Willey, 1981). But the concept of better resource use raises the question of how the yield advantages of intercropping are likely to be affected by the level of resource availability.

In the rainfed semi-arid tropics water is one of the most limiting resources for crop growth. Rainfall is usually low and highly variable and crops are often subjected to drought, particularly on light-textured soils with low moisture-holding capacity. Lack of moisture is a major cause both of low yields and of marked instability of yields from season to season.

To date, no serious attempt has been made to examine the effects of moisture availability on intercropping advantages. Fisher (1977) tried to explain differences in the results of four intercropping experiments in terms of prevailing moisture availabilities but comparisons between the experiments were confounded with differences in crop species, genotype, and plant population. Based on two experiments with a maize/bean combination, between which the only confounded factor was a change in maize genotypes, Fisher concluded that intercropping was advantageous under good moisture supply but disadvantageous under poor moisture supply. However, in these two experiments the maize/bean system had a higher total plant population than the sole crops and so almost certainly had a greater moisture demand.

This paper describes two experiments that examined the performance of 'replacement' intercropping systems (i.e. where total plant population in intercropping was equivalent to that in either of the sole crops) across a range of moisture regimes that were imposed using line-source sprinkler irrigation. The systems were based on sorghum, millet and groundnut, three crops which are highly adapted to the semi-arid environment and which are commonly grown both as sole crops and intercrops.

MATERIALS AND METHODS

Site and seasons

The experiments were conducted at ICRISAT Center on a tropical red soil (Alfisol: Udic Rhodostalf) with an available water holding capacity of 90 mm. The normal rainy season is from June to September but in order to control moisture regimes the experiments were carried out from January to April when there is less expectation of rain. During the growing period in 1980 there was only 23 mm of rain, and in 1981 there was 96 mm.

Moisture regimes

The line-source sprinkler system, developed by Hanks et al. (1976), was used to create different moisture regimes. This system consists of a line of sprinklers spaced at a distance within the line not greater than 20—25% of a sprinkler's wetted diameter (Fig. 1). Its principal advantage is that the need for discard areas between moisture treatments is eleminated; so a relatively large number of treatments can be studied on a small area which is particularly useful to study basic response patterns in relatively unexplored fields such as intercropping.

Crop treatments were laid out in long plots on each side of the line source and these were subdivided into smaller plots (3 m long) representing five moisture regimes S1—S5 (Fig. 1). Water applied in each regime was quantified by collecting it in four sets of catch cans in each replicate (Fig. 1). There were 6 replicates (both sides of 3 line-sources) in 1980 and 4 replicates (2 line-sources) in 1981.

To establish the crops the whole experimental area was uniformly irrigated from sowing to 25 days after emergence. Thereafter uniform irrigations were given at 55 and 85 days to prevent complete failure of crops at the drier extremes of the moisture treatments. Moisture gradients were imposed by giving line-source irrigations at 35, 45, 65, 75, and 95 days.

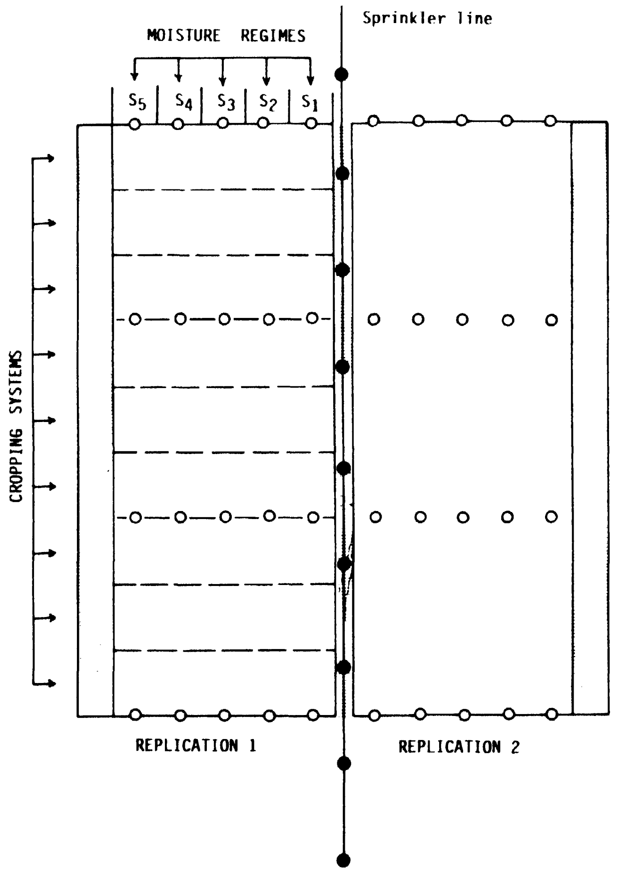

Fig. 1. Layout of the experiment (1981) showing two of the replications. Open circles indicate the positions where applied water was collected for measurement. Shaded areas indicate the border discards.

Averaged over the two experiments, actual water received through uniform irrigations and rainfall was 286 mm. Water application through the line-source, over the whole season, ranged from 298 mm at S1 to 11 mm at S5. Total water received was thus 584, 516, 420, 342, and 297 mm for S1 to S5, respectively; these were equal to 64, 57, 46, 38, and 33 percent of the open pan evaporation recorded during experiments at the nearby meteorological station.

Cropping systems

The cropping systems studied in both years are shown in Table 1.

TABLE 1

Cropping systems

Sole crops		Intercrops	
Sorghum	(S)	1 row sorghum : 2 rows groundnut	(SGG)
Millet	(M)	1 row sorghum : 3 rows groundnut	(SGGG)
Groundnut	(G)	1 row millet : 1 row groundnut	(MG)
		1 row millet : 2 rows groundnut	(MGG)
		1 row millet : 3 rows groundnut	(MGGG)
		1 row sorghum : 1 row millet	(SM)

All systems were sown in 30-cm rows at right angles to the line-source. Sole crops were at their recommended optimum populations of 150 000 plants/ha for sorghum, 220 000 plants/ha for millet, and 330 000 plants/ha for groundnut. Within-row spacing for each crop was the same in intercropping as in sole cropping so all intercropping treatments were simple 'replacement' ones where the proportional population of each crop was directly related to its number of rows and the total population was equivalent to that of the sole crops.

Crop management

Pearl millet (*Pennisetum americanum* (L.) Leeke cv. BK 560), sorghum (*Sorghum bicolor* (L.) Moench cv. CSH 8R) and groundnut (*Arachis hypogaea* L. cv. Robut 33-1) were hand sown on 2 and 9 January in 1980 and 1981 respectively. All treatments were thinned to their required populations at about 25 days. A basal dressing of 18 kg N and 46 kg P_2O_5/ha was applied to the whole experimental site before sowing. Just after thinning, nitrogen was top dressed at the rate of 62 kg/ha to the sole crops of sorghum and millet and at the same rate per row to both these cereals in the intercrops. Averaged over the two years, pearl millet was harvested at 84 days, sorghum 107 days and groundnut 114 days after sowing. The harvested plot width ranged from 6 to 12 rows depending on the row pattern.

Statistical analysis

The data were statistically analysed using the method suggested by Hanks et al. (1980). This method provides a valid statistical test for the cropping systems—moisture regimes interactions discussed in this paper.

Evaluation of yield advantages in intercropping

The relative advantages of intercropping compared with sole cropping were calculated using the land equivalent ratio (LER), which is defined as the relative land area that would be required as sole crops to produce the yields achieved in intercropping. For an individual crop, the LER is simply the yield in intercropping relative to the yield in sole cropping; for an intercropping combination the total LER is the sum of the individual crop LERs, a value greater or less than 1 indicating a yield advantage or disadvantage of intercropping, respectively. To indicate the relative advantages of intercropping at any given moisture regime, LERs were calculated using sole crop yields from the same moisture regime treatment as the intercrop.

RESULTS

The responses to moisture stress were very similar in both the years of experimentation. Illustrating this similarity with responses of the sole crops, the reductions in reproductive yields of millet, sorghum, and groundnut at S5 (most stressed) compared with yields at S1 (least stressed) were 56, 82, and 92% in 1980 and 61, 80, and 96% in 1981. All subsequent data are therefore presented as means over the two years.

Response of sole crops to moisture stress

Total dry matter production in all three sole crops declined as the degree of moisture stress increased from S1 to S5 (Fig. 2A). The decline was greater in sorghum than in millet or groundnut.

In millet the decline in grain yield with increase in stress (Fig. 2B) was similar to the decline in dry matter from S1 to S3 but it was slightly greater from S3 to S5 because of a small decrease in harvest index (Fig. 2C). In sorghum the decline in grain yield with increase in stress was consistently greater than the decline in dry matter (Fig. 2B) because of a marked decrease in harvest index (Fig. 2C). In groundnut the decline in reproductive yield (pod yield) relative to dry matter yield was even greater than in sorghum with the harvest index falling from 34% at S1 to as low as 3% at S5 (Fig. 2C).

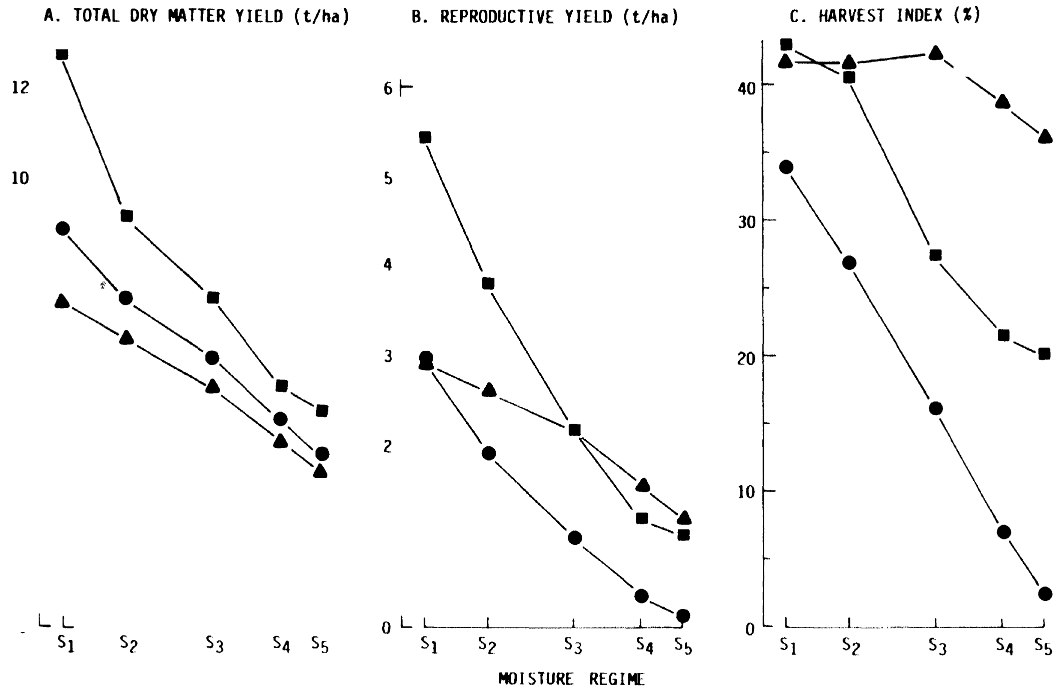

Fig. 2. Effect of moisture regime on the total dry matter and reproductive yields, and harvest indices of the sole crops of sorghum (■——■), millet (▲——▲), and groundnut (●——●). Standard errors of mean for comparing moisture levels within the cropping system: TDM — sorghum 0.211, millet 0.163, groundnut 0.167; reproductive yield — sorghum 0.134, millet 0.085, groundnut 0.064; harvest index — sorghum 2.1, millet 1.9, groundnut 1.6.

Summarising the reproductive yield responses to increasing moisture stress, therefore, groundnut showed the biggest decrease, sorghum rather less, and millet the least.

Response of intercrops to moisture stress

Sorghum/groundnut

For both sorghum and groundnut in the SGG intercrop the relative reduction in total dry matter due to increase in moisture stress was similar to that in the sole crops; so individual crop LERs were fairly constant, ranging between 0.52 to 0.62 (Fig. 3A). Since sown proportion was one third sorghum to two thirds groundnut, the similar LERs for the two crops means that sorghum must have been the more competitive crop. Total LER at S1 was only 1.03, and it ranged between 1.13 and 1.19 for the S2—S5 stress treatments, but these LER values were not significantly greater than 1.

Grain yields of sorghum and groundnut in SGG decreased much less than those of their sole crops in response to the increasing moisture stress (Fig. 3B), since the decrease in the harvest indices of these crops in SGG was not as sharp as in sole cropping. The result was that the LERs of intercropped

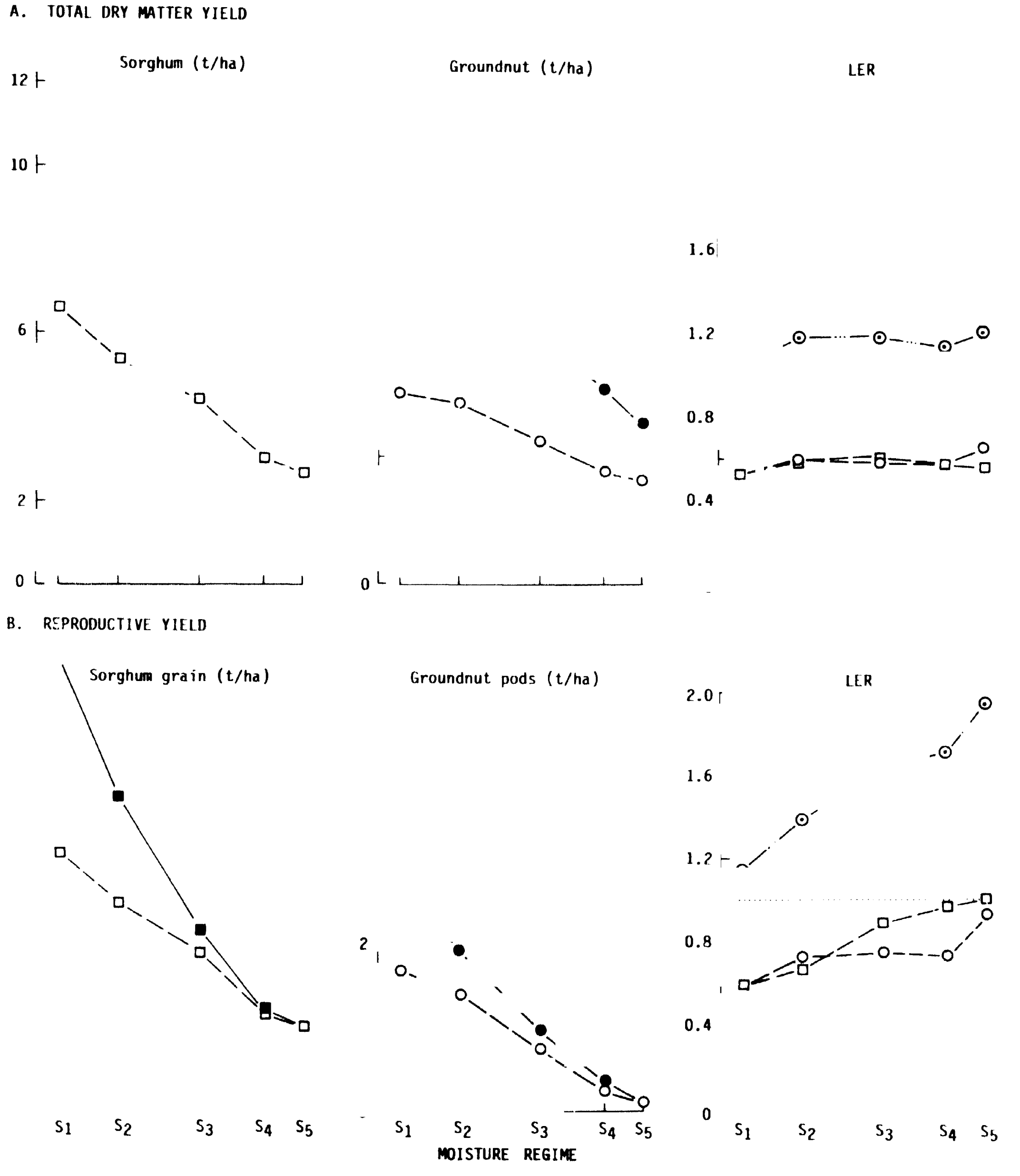

Fig. 3. Effect of moisture regime on yields and LERs of a 1 sorghum : 2 groundnut intercrop (SGG). (■——■) Sole sorghum; (□- - - -□) intercrop sorghum; (●——●) sole groundnut; (○- - - -○) intercrop groundnut; (⊙— · · · —⊙) total LER. Standard errors of means for comparing sole and intercrops at the same moisture regime (t/ha) : sorghum TDM, 0.218; sorghum grain, 0.107; groundnut TDM, 0.156; groundnut pods, 0.071. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

sorghum and groundnut increased with the degree of moisture stress. The sorghum LER increased significantly from 0.57 at S1 to 1.00 at S5. Thus despite the fact that sorghum in intercropping was sown on only one third of the area, at the severe S5 stress it produced as much grain yield as the full sole crop. The increase in groundnut LER was more variable but it significantly increased from 0.57 at S1 to 0.93 at S5 (i.e. 93% of the full sole crop). Combining these individual values there was a significant increase in the total LERs from 1.14 at S1 to 1.93 at S5; in other words the relative

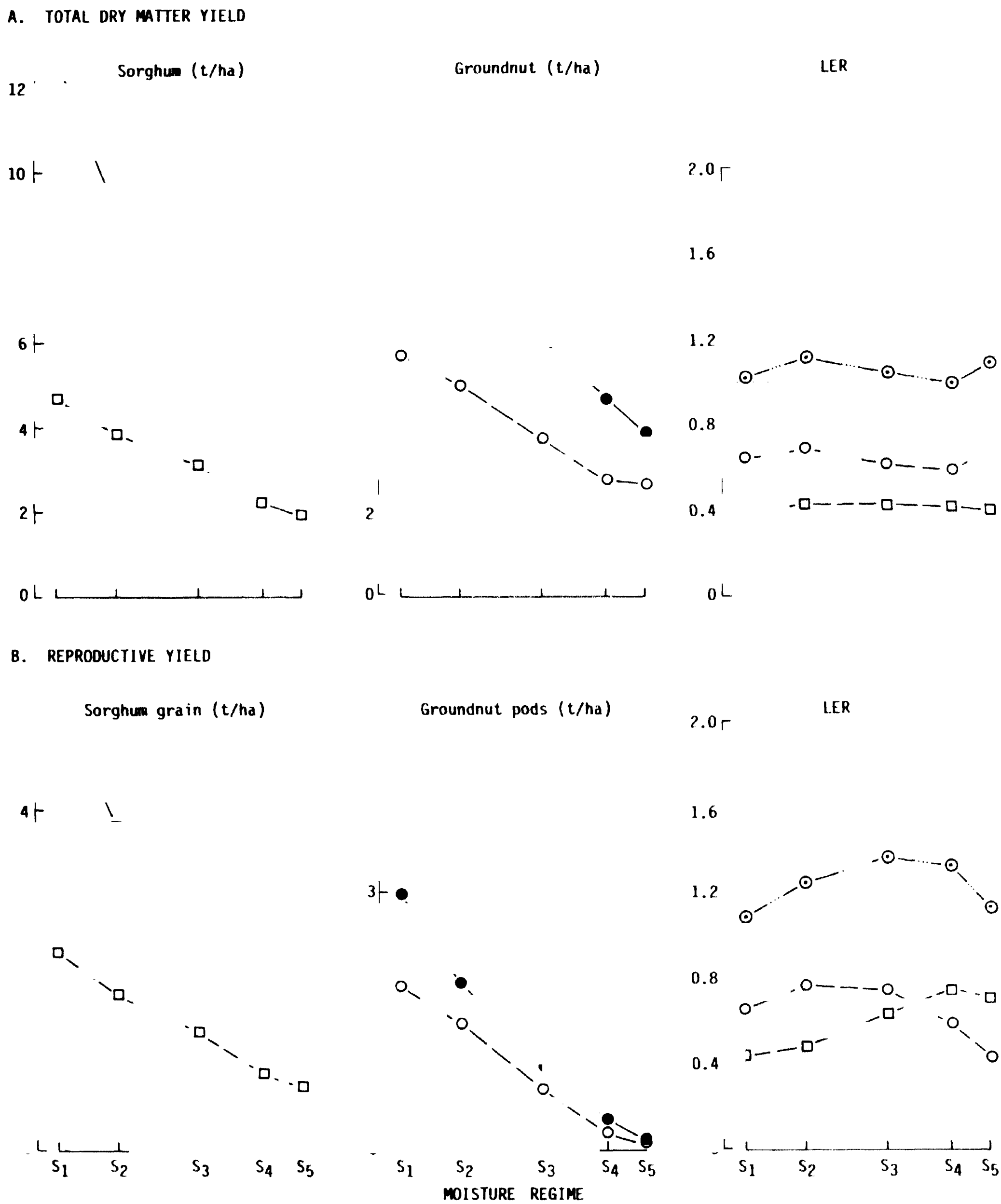

Fig. 4. Effect of moisture regime on yields and LERs of 1 sorghum : 3 groundnut intercrop (SGGG). (■——■) Sole sorghum; (□- - - - - □) intercrop sorghum; (●——●) sole groundnut; (○- - - - - ○) intercrop groundnut; (⊙— · · · —⊙) total LER. Standard errors of mean for comparing sole and intercrops at the same moisture regime (t/ha) : sorghum TDM, 0.218; sorghum grain, 0.107; groundnut TDM, 0.156; groundnut pod, 0.071. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

yield advantage of intercropping compared with growing sole crops increased from 14% under the least moisture stress up to a very considerable 93% under the severest moisture stress.

In the SGGG intercrop the reduction in dry matter yields due to moisture stress were similar to those in the sole crops so none of the dry matter LERs showed any consistent changes (Fig. 4). Individual LERs were around 0.40 for sorghum and between 0.58 and 0.69 for groundnut, again reflecting the greater competitive ability of sorghum considering the 25 : 75 sown proportion. The total LER averaged only a little over 1, so there was no evidence of any intercropping advantage for dry matter yields. For reproductive yield the sorghum LER increased significantly with increase in stress reaching a peak value of 0.74 at S4. The groundnut response was quite different from

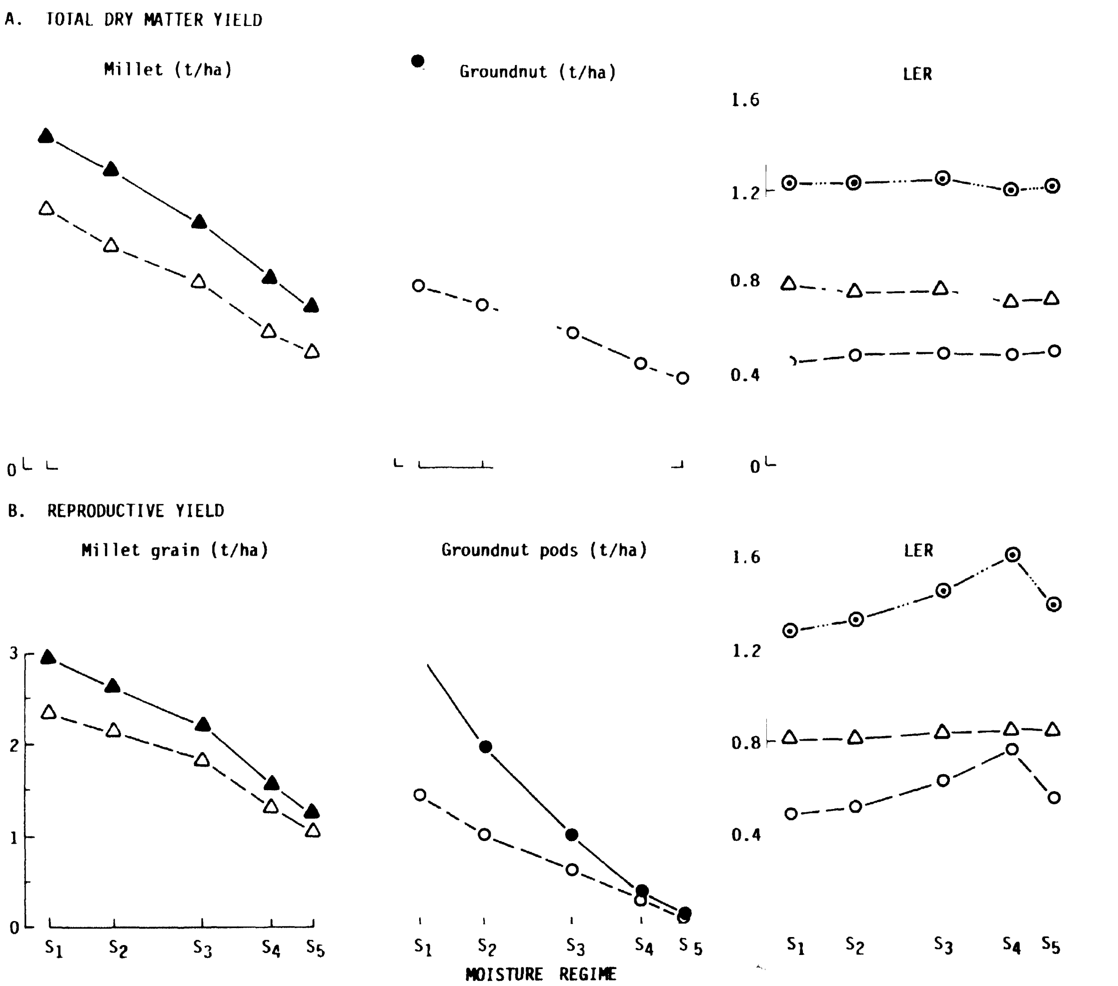

Fig. 5. Effect of moisture regime on yields and LERs of a 1 millet : 1 groundnut intercrop (MG). (▲——▲) Sole millet; (△- - - -△) intercrop millet; (●——●) sole groundnut; (○- - - -○) intercrop groundnut; (⊙— · · · —⊙) total LER. Standard errors of mean for comparing sole and intercrops at the same moisture regime (t/ha) : millet TDM, 0.121; millet grain, 0.066; groundnut TDM, 0.156; groundnut pods, 0.071. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

that in SGG; the pod yield LER increased to 0.76 at S2, but it declined with further increase in stress and was significantly lower at S5 than at S2. There were no significant differences between total LERs in SGGG but there was a smooth pattern of increase to a maximum 1.37 at S3, falling to 1.13 at S5.

Millet/groundnut

In MG the total dry matter LERs at S1 were 0.78 for millet and 0.45 for groundnut (Fig. 5) so, given the equal sown proportions, the cereal was again the more competitive component. The total LER at S1 (1.23) was

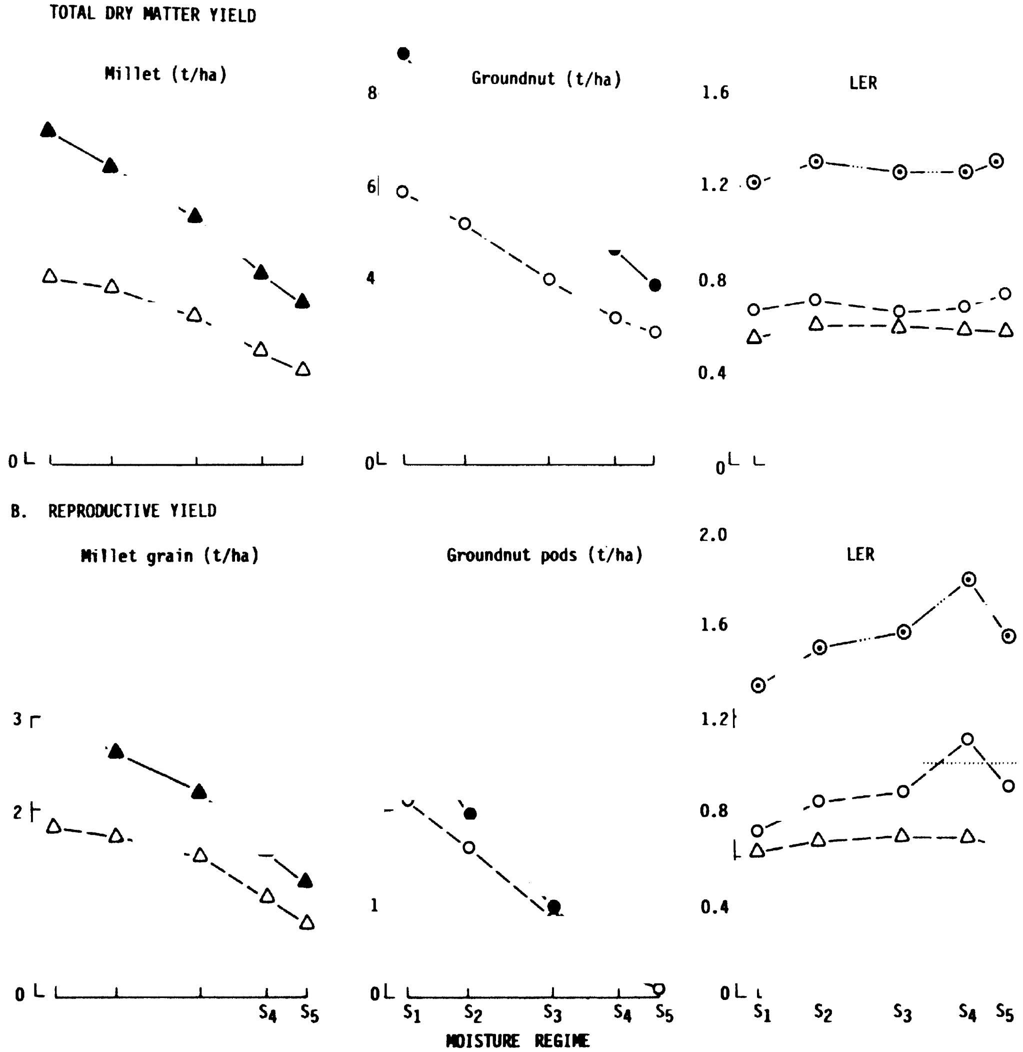

Fig. 6. Effect of moisture regime on yields and LERs of a 1 millet : 2 groundnut intercrop (MGG). (▲——▲) Sole millet; (△— — — △) intercrop millet; (●——●) sole groundnut: (○ — — — ○) intercrop groundnut; (⊙— · · · -⊙) total LER. Standard errors of mean for comparing the sole and intercrops at the same moisture regime (t/ha) : millet TDM, 0.121; millet grain, 0.066; groundnut TDM, 0.156; groundnut pods, 0.071. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

higher than with sorghum/groundnut but similar to that in the other millet/groundnut studies (Reddy and Willey, 1981). With increase in moisture stress there was a small decrease in LER for millet and a small increase for groundnut but no overall change in total LER.

Although differences were not significant, the overall effects of moisture stress on reproductive yields in MG were similar to that in sorghum/groundnut intercrops in that the total LER increased with stress, showing a peak yield advantage of 61% at S4. However, the effects on component crops were very different because the changes in total LER were determined almost entirely by changes in the groundnut LER which increased from 0.48 at S1 to 0.76 at S4. This was again mainly because the harvest index of groundnut in MG did not decrease as sharply as in the sole groundnut with increased stress.

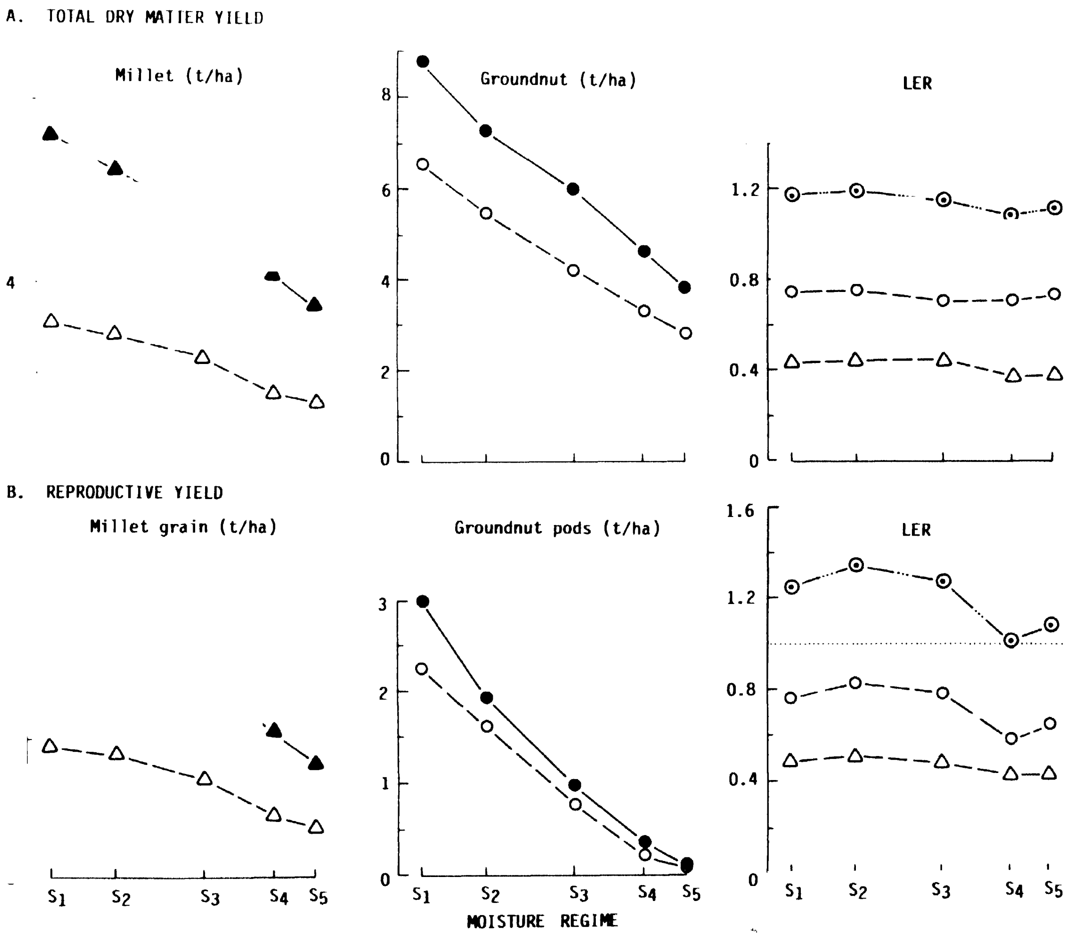

Fig. 7. Effect of moisture regime on the yields and LERs of a 1 millet : 3 groundnut intercrop (MGGG). (▲——▲) Sole millet; (△— — —△) intercrop millet; (●——●) sole groundnut; (○— — —○) intercrop groundnut; (⊙— · · · —⊙) total LER. Standard errors of mean for comparing the sole and intercrops at the same moisture regime (t/ha) : millet TDM, 0.121; millet grain, 0.066; groundnut TDM, 0.156; groundnut pod, 0.071. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

In general MGG and MGGG showed trends similar to MG (Figs. 6 and 7). Individual crop LERs for total dry matter were little affected by change in moisture stress though groundnut LERs increased and millet LERs decreased as the number of groundnut rows increased. Total LERs for dry matter averaged 1.27 in MGG and 1.14 in MGGG. For reproductive yields, MGG

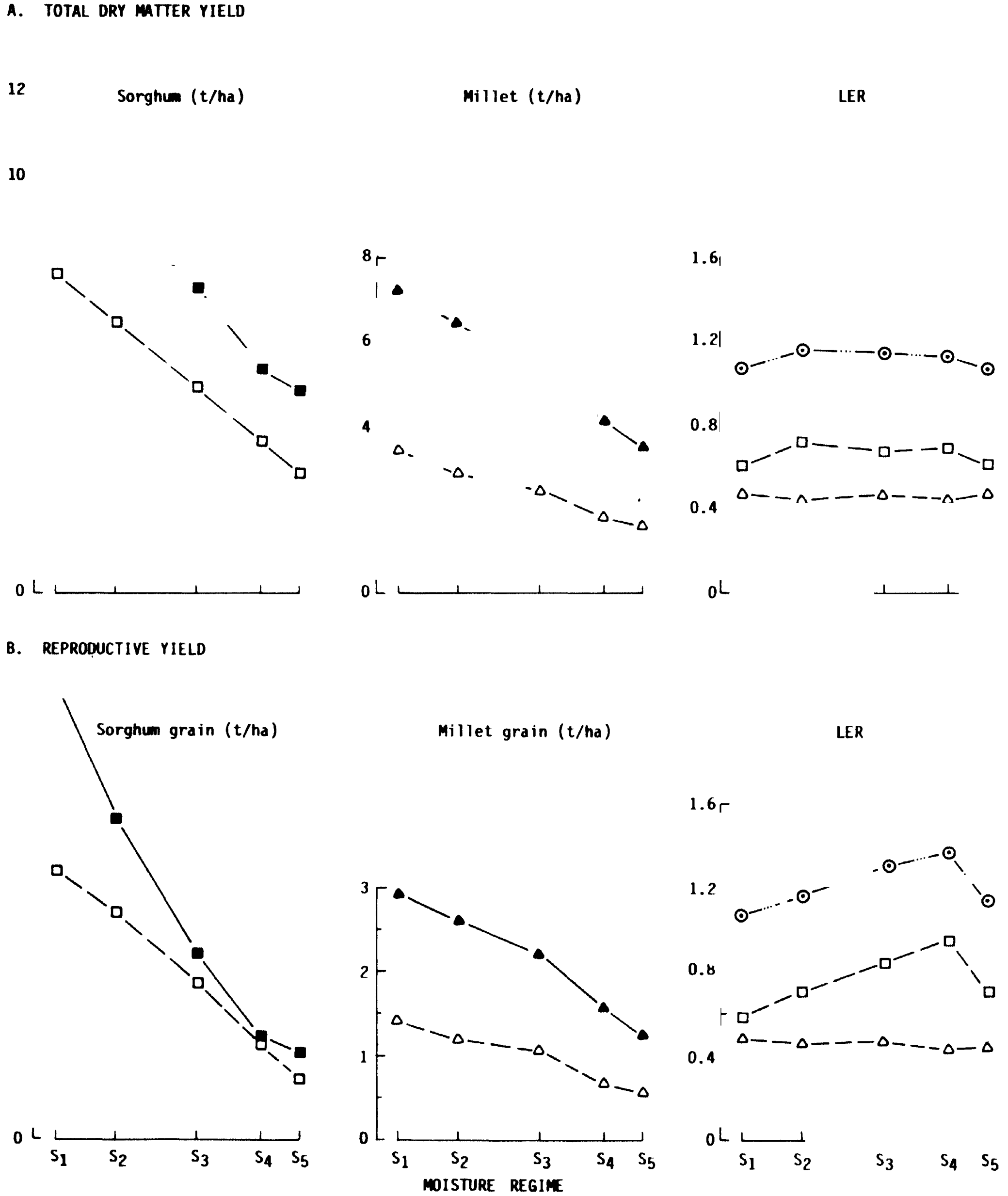

Fig. 8. Effect of moisture regime on the yields and LERs of a 1 sorghum : 1 millet intercrop (SM). (■——■) Sole sorghum; (□— — —□) intercrop sorghum; (▲——▲) sole millet; (△— — —△) intercrop millet; (⊙— · · · —⊙) total LER. Standard errors of mean for comparing sole and intercrops at the same moisture regime (t/ha) : sorghum TDM, 0.218; sorghum grain, 0.107; millet TDM, 0.121, millet grain, 0.066. Standard errors of mean for comparing total LERs between different moisture regimes : grain, 0.129; TDM, 0.0388.

was very similar to MG, an increasing groundnut LER being largely responsible for a significant increase in total LER up to a peak value of 1.78 at S4. In MGGG the peak LER of 1.34 occurred at S2.

Sorghum/millet

In SM the sorghum was a little more competitive than the millet, producing dry matter LERs between about 0.60 and 0.70 compared with less than 0.50 for millet (Fig. 8). Dry matter LERs were little affected by moisture stress and total LERs ranged between 1.06 and 1.15. For grain yields, a significant increase in sorghum LER was responsible for an increase in total LER from 1.06 at S1 to a peak value of 1.36 at S4.

DISCUSSION AND CONCLUSIONS

Considering reproductive yield of the three sole crops, millet was least affected by increase in stress, probably because this crop was the earliest maturing (84 days) and so may have escaped the greater stress which tended to build up as the season advanced. Millet was also the crop least affected by moisture stress in intercropping, showing little change in its LER and so making little contribution to changes in intercropping advantages in response to stress. In contrast, sorghum made a major contribution to changes in intercropping advantages because in all three combinations in which this crop occurred (SGG, SGGG and SM) its grain yield LER increased significantly with increase in moisture stress up to maximum values at either S4 or S5. Groundnut also showed marked changes in its pod yield LER: in the SGG and MGG treatments its LER increased with increase in stress right up to the S5 treatment; in the other combinations, an increase in LER up to a moderate degree of stress was typically followed by a decrease under severe stress, especially in SGGG and MGGG.

These changes in individual crop LERs for reproductive yield produced a reasonably consistent pattern of changes in total LERs across different combinations. All combinations showed some increase in total LER with increase in stress from S1 to S2. The treatments with single or double groundnut rows showed increases in total LER with further increase in stress, producing very high yield advantages at either S4 or S5. The treatments with triple groundnut rows showed a decline in total LER at severe stress, so their maximum LER values were lower than in the single or double groundnut row treatments and they occurred at only moderate degrees of stress. The SM intercrop showed a pattern similar to the single and double row groundnut treatments, with a peak LER at S4 but the yield advantage from this combination was relatively less.

The mechanisms which produced the yield advantages in these combinations, and which gave different magnitudes of yield advantage with different degrees of moisture stress, could not be directly identified because no measurements of resource use were possible in these experiments. However, as was emphasized earlier, if two crops use different parts of a given resource or use that in rather different ways, an intercrop of two crops may be able to make fuller or more efficient use of that resource and so produce higher yields than can be achieved by growing separate sole crops. One possible mechanism in the present experiments could have been that the different crops had different rooting depths. It has been shown that the major portion of groundnut roots are rather shallower than cereal roots (Gregory and Reddy, 1982), and this could have contributed to the advantages in the cereal/groundnut combinations. The larger intercropping advantages that occurred under greater degree of stress might be a result of increasing expression of complementarity of the intercrops which have different rooting depths, as moisture resource became more limiting. The lower yield advantages in the triple groundnut row treatments compared with the single or double row treatments could have been because the cereal and groundnut planting arrangement was not sufficiently intimate to take full advantage of complementary interactions between the crops.

Another mechanism that might have operated in the groundnut combinations was that shade from the cereal might have provided a favourable microclimate for the groundnut intercrop under drought. This may explain the smaller advantages in the triple groundnut row combinations because cereal rows in these combinations may have been too wide to produce their most beneficial shading effect. In fact this mechamism could also explain the decreases in groundnut LER and total LER under severe stress because the much reduced cereal growth under these conditions tended to produce less shade than under more favourable moisture regimes.

It must be emphasised, however, that where the water resource is concerned, plant populations of intercropping systems might well be very critical in determining whether a potential complementary effect between the crops results in a yield advantage. In the experiments reported here, total intercrop population was the same as the sole crops and the population of each individual crop was therefore only a proportion of its sole crop. In this situation some complementarity between crops can result in component crops experiencing less competition in intercropping than in sole cropping. Conversely, where total plant populations are higher in intercrops than in sole crops there can be greater competition in intercropping than in sole cropping. Clearly, higher population intercrops suffer even greater yield reductions than sole crops under conditions of moisture stress, and it seems likely that this was what occurred in the experiments described by Fisher (1977).

In all three of the crop combinations examined there was evidence of some increase in relative reproductive advantages with increase in stress. In some intercrop treatments the relative advantage under the most severe stress was less than under moderate stress, and it seems likely that there are critical interactions between optimum plant population and spatial arrangement in intercropping and the level of stress. Over the wide range of stress treatments studied in these experiments, however, in all except one intercrop system (MGGG) the yield advantage under the severest stress was still higher than under the least stress. Moreover, there was no instance in which intercropping gave lower relative yields than sole cropping (i.e. total LER less than 1), even under the severest stress.

The factors affecting these drought responses need further study. Nevertheless, it seems possible to develop intercropping systems that are particularly beneficial when moisture is limiting. These systems could serve as a means of raising the low yields which are characteristic of the dry areas and improving the yield stability by reducing yield losses in low rainfall years.

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(b) Drawings should be fully annotated, the size of the lettering being appropriate to that of the drawings, but taking into account the possible need for reduction in size (preferably not more than 50%). The page format of the journal should be considered when designing drawings.
(c) Photographs must be of good quality, printed on glossy paper.
(d) Figure captions should be supplied on a separate sheet.

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