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LIGHT USE, WATER UPTAKE AND PERFORMANCE OF INDIVIDUAL COMPONENTS OF A SORGHUM/GROUNDNUT INTERCROP

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SUMMARY

The productivity of each component of a sorghum/groundnut intercrop and its constituent sole crops is determined in terms of a 'Crop Performance Ratio' (CPR) defined as the productivity of an intercrop per unit area of ground compared with that expected from sole crops sown in the same proportions. The CPR allows productivity, intercepted radiation and seasonal transpiration to be compared so that conversion coefficients for radiation (e; g MJ^{-1}) and dry matter/water ratios (q; g kg^{-1}) can be calculated for each intercrop component and its constituent sole crops. In this experiment, CPR for total dry weight in the intercrop was 1.08 and that for reproductive yield was 1.27. These advantages in overall productivity and yield were typical of those reported elsewhere for sorghum/groundnut intercrops. The proportional increase in total dry matter in the intercrop was largely a result of its greater interception of radiation. The further advantage in reproductive yield was a consequence of an improved harvest index in the sorghum component of the intercrop (0.64) compared with that of its sole crop counterpart (0.55).

S. N. Azam-Ali, R. B. Matthews, J. H. Williams y J. M. Peacock: *Aprovechamiento de luz y agua y rendimiento de los componentes individuales de un cultivo intercalado de sorgo/cacahuete.*

RESUMEN

La productividad de cada componente de un cultivo intercalado de sorgo y cacahuete y sus monocultivos constituyentes se determina en términos de una 'relación de rendimiento del cultivo' (CPR), que se define como la productividad de un cultivo intercalado por superficie unitaria de tierra comparado con la que se espera de monocultivos sembrados en las mismas proporciones. La CPR permite comparar la productividad, la radiación interceptada y la transpiración estacional de modo que se puedan calcular los coeficientes de conversión para la radiación (e; g MJ^{-1}) y relaciones de materia seca/agua (q; g kg^{-1}) para cada componente del cultivo intercalado y sus monocultivos constituyentes. En este ensayo, la CPR para la materia seca total en el cultivo intercalado fue 1,08 y la del rendimiento reproductivo fue 1,27. Estas ventajas en la productividad y rendimiento globales fueron características de las que se han informado en otros estudios para los cultivos intercalados de sorgo y cacahuete. El aumento proporcional en la materia seca total en el cultivo intercalado ocurrió en gran parte como resultado de su mayor intercepción de la radiación. La ventaja adicional en el rendimiento reproductivo se dio como consecuencia de un índice de cosecha mejorado en el componente sorgo del cultivo intercalado (0,64) comparado con el del monocultivo correspondiente (0,55).

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INTRODUCTION

Although multiple cropping systems were the first types of organized agriculture (Francis, 1986) their biological complexity has deterred scientists from analysing their productivity, particularly in relation to the capture and use of physical resources. Nevertheless, there is substantial agronomic evidence that the yields of many intercrops may exceed the combined yields of their component species grown as sole crops (e.g. Willey, 1979; Willey and Rao, 1981; Ahmed and Rao, 1982). For example, intercrops of sorghum and groundnut have shown yield advantages of between 25 and 40% (Willey and Osiru, 1972; Wahau and Miller, 1978). A fundamental understanding of how such intercrops capture and use resources would provide a more scientific basis for recommending appropriate combinations of species and planting arrangements for intercropping at different locations. Furthermore, a knowledge of how the microclimate of an intercrop varies from that of its constituent sole crops may have implications for plant breeding. Most selection programmes are restricted to sole crops but recommendations based on such trials are often used to select genotypes for intercropping. However, there is evidence that the highest yielding genotypes in sole cropping do not necessarily remain so when grown as intercrops (Francis *et al.* 1976; Wein and Smithson, 1979) and Rao *et al.* (1980) have emphasized the need for selecting genotypes specifically for intercropping.

The responses of many individual crops to physical factors such as light, water or temperature are well known (e.g. Monteith, 1977; Doyle and Fischer, 1979; Ong and Monteith, 1984). However, such relations have rarely been established for intercrops where two or more species are grown in close association. Where the productivity of an intercrop has been correlated with the capture or use of an individual resource such as light (Sivakumar and Virmani, 1980) or water (Reddy *et al.*, 1980) this has been in terms of the total amount used by the whole intercrop, not with that used by each component species. This omission is largely because of the difficulties of partitioning the use of resources between species. Marshall and Willey (1983) successfully partitioned the radiation intercepted by a millet/groundnut intercrop into that captured by each species. They found that the increased productivity of the intercrop could be ascribed to a combination of greater fractional interception by the millet and a greater conversion efficiency (e; g MJ^{-1}) by the groundnut, when compared with their respective sole crops.

Few studies have successfully partitioned the transpiration from an intercrop. Where this has been reported, actual values of transpiration have been estimated by assuming that the dry matter/water ratio (q; g kg^{-1}) of each species in the intercrop remains identical to that of its sole counterpart (e.g. Reddy *et al.*, 1980). Thus, the transpiration from each component is inferred from a knowledge of the dry matter produced by each species in the intercrop and in the comparable sole crop. However, the conservative nature of q for sole crops of a particular species (e.g. Stewart *et al.*, 1975; Doyle and Fischer, 1979) may not necessarily apply in intercrops where roots and shoots of morphologically different species are competing for resources.

To our knowledge there have been no *direct* measurements of transpiration from the elements of an intercrop. Azam-Ali (1983, 1984) showed that measurements of leaf diffusive resistance, obtained using a porometer, could be combined with allied measurements of microclimate and leaf area to estimate transpiration from sole crops of millet or groundnut grown on stored water. Transpiration estimated by this technique showed good agreement with contemporary measurements obtained using a neutron probe. Although the porometer technique is not a practical alternative to the neutron probe as a means of measuring the *amount* of water transpired by sole crops, the technique does have a unique application for intercrops where it can be used to estimate the *proportion* of water transpired by each component. When the relative transpiration of each intercrop component is superimposed on contemporary neutron probe measurements from the whole intercrop, the combined method provides a means of calculating the actual transpiration, and therefore the value of q, for each intercrop component.

This paper describes the growth and yield of a sorghum/groundnut intercrop and its component sole crops grown in the post-rainy season in central India. The seasonal accumulation of dry matter and reproductive yield are analysed in terms of the intercepted radiation and transpiration from each species in the intercrop and the comparable sole crops.

MATERIALS AND METHODS

Experimental design and management

The experiment was on a medium depth Alfisol at the ICRISAT Centre, Patancheru, India (18° 38′ N, 78° 21′ E). There were three treatments: an intercrop sown as one row of sorghum (*Sorghum bicolor*, cv. CSH-8) and three rows of groundnut (*Arachis hypogaea*, cv. Kadiri 3), and sole crops of the two species. The experimental design was a Latin square with three replicates; each plot was 30 × 24 m.

Seeds were hand-sown on 22 November 1984 in rows 30 cm apart aligned east–west. After emergence, groundnut rows were thinned to an intra-row distance of 10 cm and sorghum to an intra-row distance of 20 cm. To promote establishment the plots were sprinkler irrigated three times until 20 days after sowing (DAS). There were two subsequent irrigations: at 80 DAS and at 103 DAS after the final harvest of sorghum. No rain fell during the experiment. Weekly pest and disease control was maintained by hand-spraying and the field was periodically hand-weeded throughout the season.

Growth analysis

Between 21 and 138 DAS, two samples per plot were randomly harvested each week for growth analysis. In the sole crops, each sample contained two adjacent 1 m rows in the sorghum and a single 1 m row in the groundnut, giving an average of 10 plants in each plot. In the intercrop, each location contained one row of sorghum on either side of three rows of groundnut. Each groundnut row in the intercrop was treated independently and hereafter the northernmost row (least shaded) is referred to as G1, the middle row as G2 and the southernmost as G3. Numbers of leaves, pegs and pods (groundnut) or panicles (sorghum) were recorded. After leaf area had been measured with a planimeter (Licor 3000) each component was oven-dried at 80°C for 48 h and its dry weight recorded. The final harvest of sorghum in the sole plots and the intercrop was at 103 DAS and the final harvest of groundnut was at 138 DAS.

Radiation measurements

Tube solarimeters were installed in all plots soon after establishment. There were two 90 cm solarimeters per plot below the canopies of the sole crops, each tube spanning three adjacent rows at ground level. In the intercrops there were three 120 cm solarimeters per plot at ground level, each tube spanning the two sorghum rows and three groundnut rows. The outputs from the solarimeters were recorded on a data logger (Campbell Scientific Ltd) housed adjacent to the field. Daily fractional interception per plot, f, was calculated as the difference between the radiation received by the below-canopy solarimeters and that received by a solarimeter mounted 2 m above ground level. In order to partition the proportion of radiation intercepted by each species in the intercrop, the irradiance above the groundnut component was measured using solarimeters positioned longitudinally above each row in the intercrop. Accumulated intercepted radiation was calculated from a knowledge of the daily irradiance (MJ m^{-2}) measured using a Kipp-Zonen solarimeter at a meteorological station within 200 m of the field.

Changes in soil moisture content and transpiration

The changes in soil moisture from each plot were measured at weekly intervals between 23 to 105 DAS using a neutron probe (Troxler Instruments).

Transpiration from each component of the intercrop and the sole crops was estimated on 10 occasions between 50 and 103 DAS using the porometer technique described by Azam-Ali (1984). This required measurements of stomatal resistance, leaf temperature, vapour concentration difference and boundary layer resistance as described in the following sections.

Stomatal resistance

A diffusive resistance porometer (Li1600, Licor Instruments) was used as described by Azam-Ali (1984). The sorghum canopy was treated as two layers: from 0 to 50 cm above ground level, and any material above 50 cm. Groundnut plants never extended above about 25 cm and were therefore treated as a single layer. Measurements were made at 0800, 1000, 1200, 1400 and 1600 Indian Standard Time. In plots containing sorghum, the abaxial and adaxial surface resistance, r_s, was measured on single leaves in each layer of two randomly sampled plants. Measurements were made at the mid-portion of a leaf parallel with the mid-rib. In plots containing sole groundnut, abaxial and adaxial resistance was measured on a single leaflet of two randomly sampled plants. For groundnut in the intercrop, one leaflet per plant was measured on two plants in adjacent rows of G1, G2 and G3. Thus, r_s was measured on twelve leaves per treatment in the sole sorghum and the sorghum component of the intercrop and on six leaves per treatment in the sole groundnut and each component groundnut row of the intercrop.

Leaf temperature, vapour concentration difference and boundary layer resistance

The temperature of each leaf, T_l, was measured using a copper/constantan thermocouple fitted within the cuvette of the porometer sensor head. Wet- and dry-bulb temperatures (T_w, T_d) for the same leaf layer, measured using an Assmann psychrometer (Cassella, London) were determined each time r_s was measured. The boundary layer resistance, r_a, was estimated periodically using wet blotting paper leaf replicas exposed at heights corresponding to the layers used in porometry. The temperature of the leaf replicas was measured using the thermocouple fitted in the Li1600 porometer and an Assmann psychrometer was used to obtain contemporary measurements of T_d and T_w at the same heights as the exposed leaves. Boundary layer resistances were calculated for each canopy layer following the method described by Azam-Ali (1984).

Objectives and terminology

The conventional index used to assess the productivity of intercrops is the Land Equivalent Ratio, or LER, which Willey (1985) defined as 'the relative land area required as sole crops to produce the same yields achieved in intercropping'. For an intercrop composed of two species, a and b:

$$\mathrm{LER}_{ab} = \mathrm{LER}_a + \mathrm{LER}_b \tag{1}$$

Thus, if $\mathrm{LER}_{ab} = 1.25$ then 25% more land would be required to achieve the same yield from sole crops as that achieved by the intercrop. The concept therefore implies a change in the total cropped area.

The objective of this study was to relate differences in total dry weight and yield per unit ground area to the capture or use of water and light. For this we have defined a Crop Performance Ratio (CPR). For each species, productivity in the intercrop can be expressed as a partial CPR, i.e. for species a:

$$\mathrm{CPR}_a = Q_{ia}/P_{ia} \, . \, Q_{sa} \tag{2}$$

where Q_{ia} and Q_{sa} are its productivity per unit area in the intercrop and sole crop, respectively, and P_{ia} is the proportion of the intercrop area sown with species a.

Thus, for an intercrop composed of two species, a and b, the Crop Performance Ratio is expressed as:

$$CPR_{ab} = (Q_{ia} + Q_{ib})/[(P_{ia} \cdot Q_{sa}) + (P_{ib} \cdot Q_{sb})] \qquad (3)$$

Because the sole crop values are multiplied by their sown proportions in the intercrop, this provides their 'expected' productivity if unit area of ground had been sown with sole crops in the same proportions as in the intercrop. A value of CPR greater than unity implies an intercrop advantage and a value less than unity an intercrop disadvantage. Unlike partial LER, the partial CPR always compares the performance of each species with unity and the departure from unity is a measure of the fractional advantage or disadvantage of the species when grown as an intercrop. In fact, partial LER and partial CPR are related so that for species a:

$$LER_a = CPR_a \cdot P_{ia} \qquad (4)$$

The concept of CPR can be extended to analyse the capture or use of a resource by an intercrop compared with its constituent species. Thus, we can calculate a CPR for the use of individual resources, such as total intercepted radiation, transpiration or nutrient uptake, in which the expected resource use by an equivalent sole crop is always unity. However, it should be noted that, unlike partial LERs, the partial CPRs of each species cannot simply be added to give the CPR for the whole intercrop.

RESULTS

Crop performance

The seasonal development of the intercrop advantage is presented in Fig. 1 At any time, the ratio of the solid and dashed lines is the CPR, either for to dry weight or reproductive yield. Sorghum was harvested at 103 DAS, thus t data presented in Fig. 1a after this date are derived from successive groundn harvests plus data from sorghum at 103 DAS. The CPR was already grea than 1 at 103 DAS for both total dry weight and reproductive yield, indicati a spatial advantage in the use of resources before the removal of sorghu Figs 1b and 1c, respectively, present the actual and expected productivit of the sorghum and groundnut components of the intercrop. For sorghum, t CPR was always greater than unity throughout the season and by final harv the sorghum component of the intercrop showed a 59% advantage in total d weight and an 85% advantage in reproductive yield compared with the s crop. This increased advantage in yield reflected an increase in the proporti of total dry matter allocated to reproductive structures. The harvest ind (panicle weight/total shoot weight) of sorghum in the intercrop was 0.64 co pared with 0.55 in the sole crop. In contrast, the CPR for groundnut ne

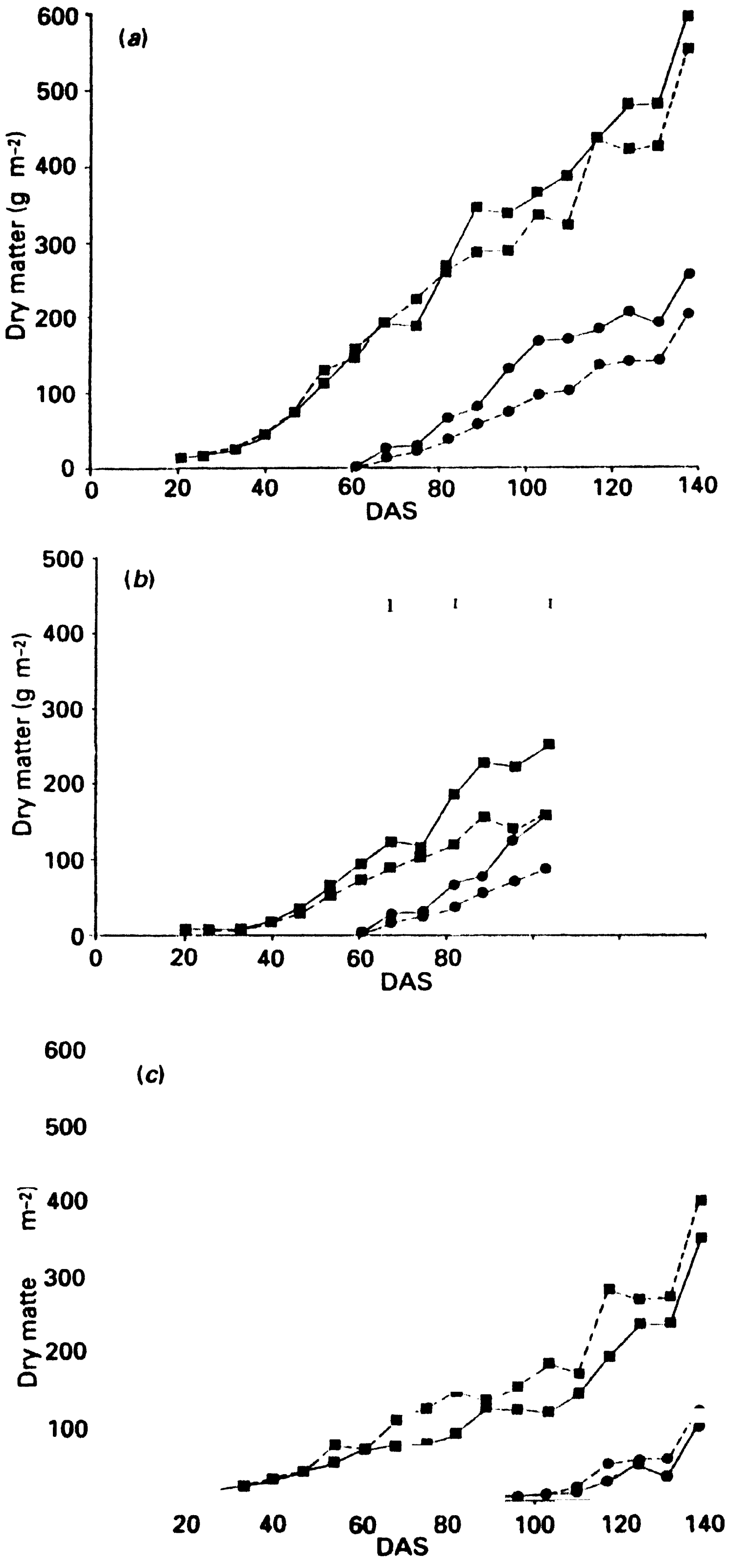

Fig. 1. Actual (——) and expected (- - -) total dry matter (■) and reproductive yield (●) (a) in the intercrop, (b) of the sorghum component in the intercrop and (c) of the groundnut component in the intercrop.

Table 1. *Contributions of various components of total dry weight and reproductive yield (g m^{-2}) and Crop Performance Ratios (CPR) at final harvest for sorghum (103 DAS) and groundnut (138 DAS) in the sole crops and intercrop (comparable Land Equivalent Ratios (LER) for total dry weight and reproductive yield are presented in parentheses)*

	Sorghum		Groundnut		
	Sole	Intercrop	Sole	Intercrop	Intercrop
Total dry weight	622	247	531	349	596
CPR	1.59 (0.40)		0.88 (0.66)		1.08 (1.06)
Reproductive yield	343	159	157	99	258
CPR	1.85 (0.46)		0.84 (0.63)		1.27 (1.09)
Leaf number	57.8	10.5	3183	2004	2015
CPR	0.73		0.84		0.84
Leaf dry weight	34.4	7.9	135.2	89.7	127.9
CPR	0.92		0.88		0.89
Leaf area index	0.53	0.11	2.30	1.53	1.64
CPR	0.83		0.88		0.88
Stem dry weight	162.6	56.9	193.0	129.6	186.5
CPR	1.40		0.90		1.00

exceeded 1 and by final harvest the disadvantage in terms of total dry weight was 12% and that for reproductive structures was 16%. Nevertheless, the increased productivity of sorghum more than compensated for yield losses in the groundnut and by final harvest the CPR of the intercrop showed an 8% advantage in total dry weight and a 27% advantage in reproductive yield. The contributions of leaves, stems and panicles to the final dry weights and reproductive yields of both sole crops and the intercrop and their respective values of CPR are summarized in Table 1.

The greater CPR for total dry weight of sorghum was a consequence of increased weights of stems and panicles, though the number, weight and area of leaves were smaller than those of the sole crop. For groundnut, CPR was always between 0.84 and 0.93. The total CPR of the intercrop confirms that its overall advantage was largely due to an increase in the weight of reproductive structures.

Resource capture

Radiation. The actual and expected values of accumulated intercepted radiation for the components of the intercrop before the removal of sorghum at 103 DAS are presented in Fig. 2. The expected values were calculated from a knowledge of the total radiation intercepted by the sole crops multiplied by their sown proportions in the intercrop. The total CPR for accumulated intercepted radiation was 1.22, which was a result of 70% greater than expected interception by the sorghum component (Fig. 2a) and 15% less than expected interception by the groundnut component (Fig. 2b).

Evaporation. The fraction of transpiration that occurred from each component, calculated using the porometer technique, was used to weight the evaporation from the whole intercrop calculated from measurements with the neutron probe. The crops were irrigated at 80 DAS and the period between 80 and 83 DAS is excluded because evaporation directly from the soil surface would have been a substantial component of total evaporation. Apart from this period, it was assumed that differences between treatments in evaporation from the soil surface were small and that the transpiration from each plot was similar to the total evaporation. This combined technique was used to calculate the cumulative transpiration from each treatment for two periods: from 50 to 77 DAS and from 83 to 103 DAS. The porometer-based estimates of fractional transpiration from each component of the intercrop are shown in Fig. 3. During the first period (50 to 77 DAS) the proportion of total evaporation from the sorghum component declined from more than 55% to less than 40% and the proportion of evaporation from the groundnut increased at a similar rate. After 83 DAS, evaporation from the sorghum component continued to decline rapidly until by 103 DAS it accounted for only about 5% of the total while evaporation from the groundnut component again continued to increase.

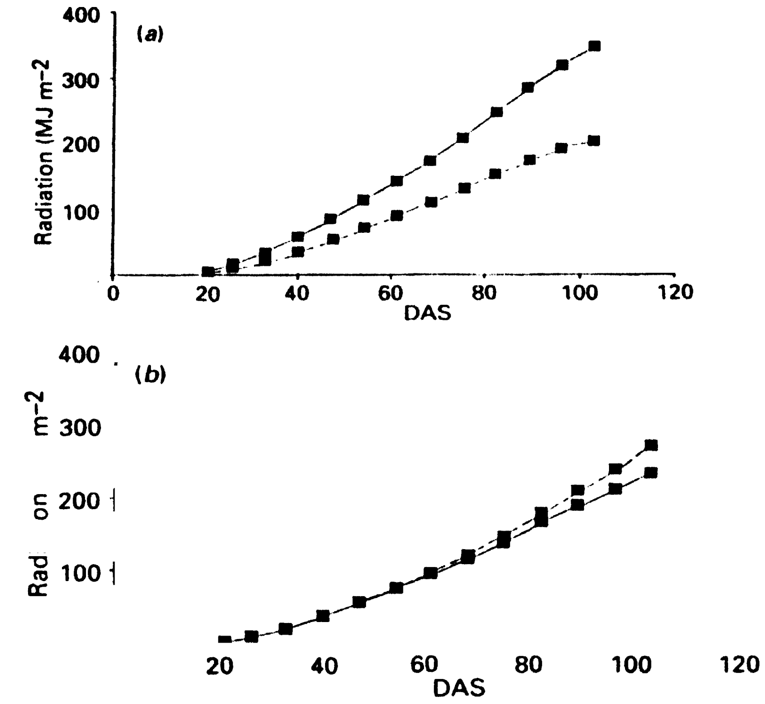

Fig. 2. Actual (——) and expected (- - -) accumulated intercepted radiation of (a) the sorghum component and (b) the groundnut component in the intercrop.

Estimates of actual and expected transpiration from the intercrop from 50 to 77 and 83 to 103 DAS, calculated as shown earlier for light interception (Fig. 2), were very similar to estimates obtained using the neutron probe (Fig. 4a). However, the porometer-based estimates of fractional transpiration from the sorghum component considerably exceeded the expected value for both periods (Fig. 4b). In contrast, that from the groundnut component (Fig. 4c) was less than expected over the same periods.

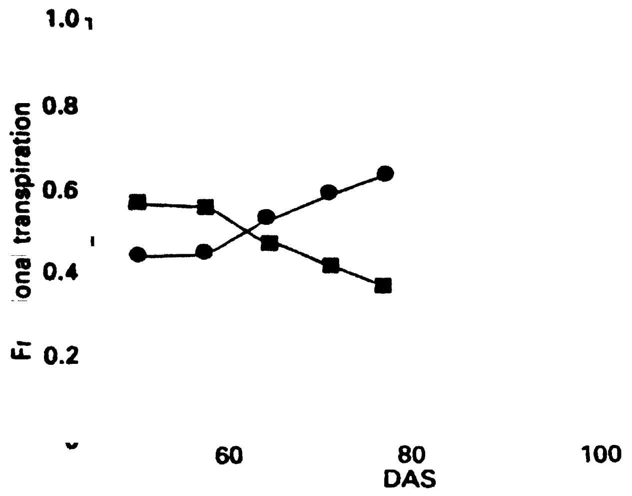

Fig. 3. Fractional transpiration of each component of the intercrop between 50 and 103 days after sowing (DAS); sorghum (■—■), groundnut (●—●).

Resource use

The observed and expected values of accumulated dry matter (TDM), light interception (S_i) and water use (E_i) from sowing until 103 DAS are presented in Table 2 with the corresponding conversion coefficients for dry matter/light (e) and the dry matter/water ratio (q). Because they were not available throughout this period, estimates of transpiration from each of the sorghum and groundnut components are not included. However, in terms of total water use, evaporation from the intercrop was similar to the expected value with a CPR for water of 1.04. Although the intercrop intercepted 22% more light than expected, its efficiency of conversion into dry matter was slightly poorer than that of the combined sole crops and this accounted for an overall CPR for total dry matter of only 1.08. The value of q for the sole sorghum was more than twice that for the sole groundnut and, overall, the value for the intercrop was slightly greater than expected on the basis of sown proportional area.

In order to partition water use between the components of the intercrop, the values for TDM, S_i, E_i and corresponding values of e and q from 50 to 77 DAS and 83 to 103 DAS are also shown with estimates of CPR for light interception and transpiration for the same periods. The intercrop intercepted between 19 and 23% more light than expected on the basis of sown proportional area during both periods but its conversion efficiency remained less than that of the sole crop. In contrast, the groundnut component of the intercrop intercepted between 7 and 22% less radiation than expected during both periods. Furthermore, its conversion efficiency was also substantially poorer than that of the sole crop between 50 and 77 DAS, though between 83 and 103 DAS the comparable values of e were similar.

Although the sorghum component transpired between 36 and 41% more water than expected, this increase was almost exactly matched by the proportional reduction in transpiration from the groundnut component and, thus,

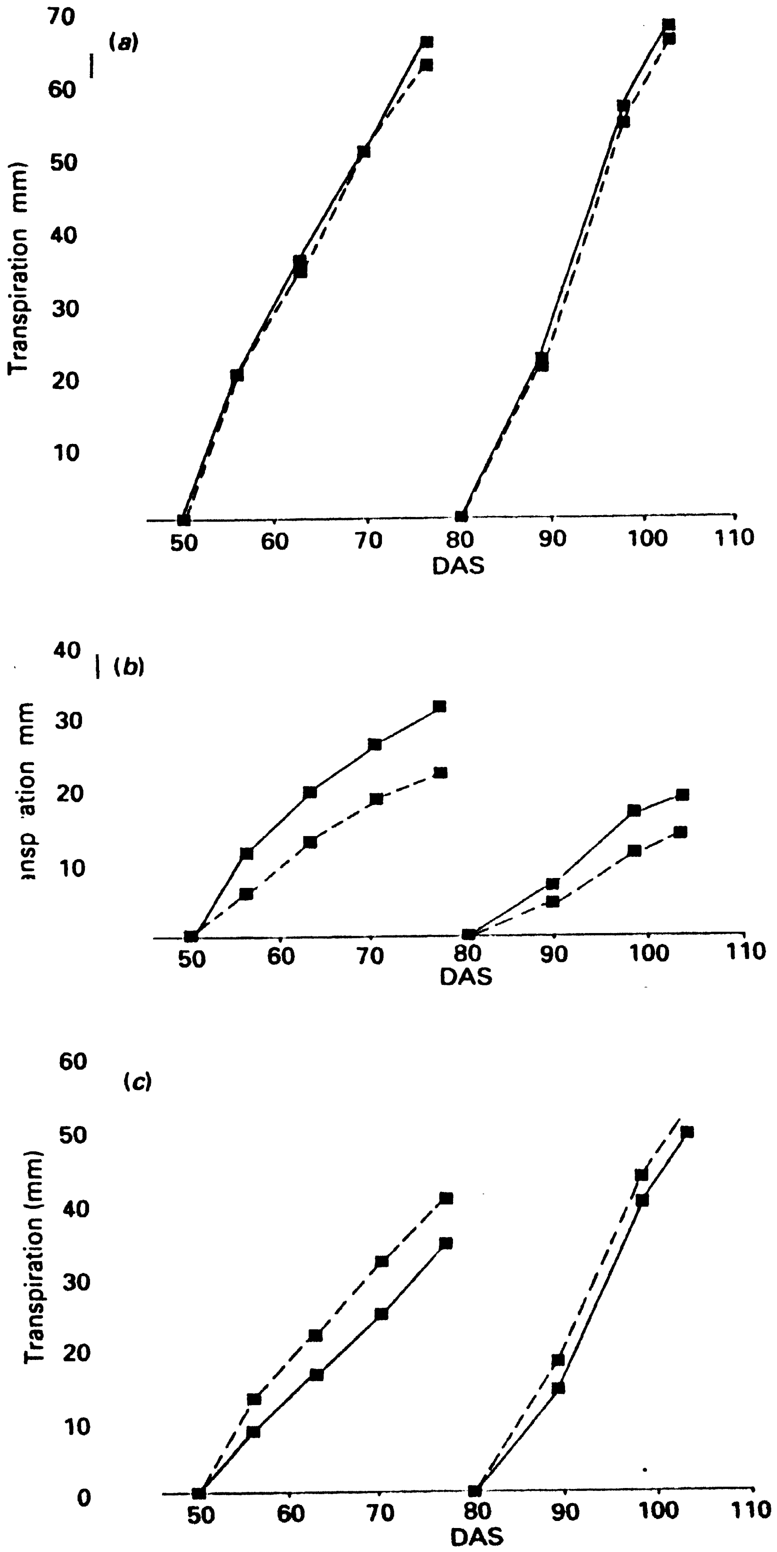

Fig. 4. Actual (——) and expected (- - -) transpiration between 50 and 77 days after sowing (DAS) and between 83 and 103 DAS (a) from the intercrop, (b) from the sorghum component of the intercrop and (c) from the groundnut component of the intercrop.

Table 2. *Total dry matter, TDM (g m^{-2}), accumulated intercepted radiation, S_i (MJ m^{-2}), transpiration, E_i (mm), and corresponding conversion coefficients for dry matter, e (g MJ^{-1}), dry matter/water ratios, q (g kg^{-1}), and Crop Performance Ratios (CPR) for a sorghum/groundnut intercrop and its components and for sole sorghum and groundnut (expected values presented in parentheses)*

	Intercrop			Sole crops	
	Total intercrop	Sorghum component	Groundnut component	Sorghum	Groundnut
0 to 103 DAS					
TDM	365 (338)	248 (156)	117 (182)	622	242
S_i	587 (482)	352 (207)	235 (275)	827	366
E_i	181 (174)			167	174
e	0.62 (0.70)	0.70 (0.75)	0.50 (0.66)	0.75	0.66
q	2.02 (1.94)			3.72	1.39
CPR (TDM)	1.08	1.59	0.64		
CPR (light)	1.22	1.70	0.85		
CPR (water)	1.04				
50 to 77 DAS					
TDM	120 (137)	87 (66)	32 (71)	263	95
S_i	200 (168)	124 (78)	84 (90)	312	120
E_i	66 (63)	31 (22)	34 (41)	89	54
e	0.60 (0.82)	0.70 (0.84)	0.38 (0.79)	0.84	0.79
q	1.83 (2.17)	2.79 (2.96)	0.93 (1.75)	2.96	1.75
CPR (TDM)	0.88	1.32	0.45		
CPR (light)	1.19	1.59	0.93		
CPR (water)	1.05	1.41	0.83		
83 to 103 DAS					
TDM	83 (72)	60 (37)	29 (35)	148	46
S_i	162 (132)	96 (50)	65 (83)	199	110
E_i	68 (66)	19 (14)	49 (52)	54	70
e	0.51 (0.55)	0.63 (0.74)	0.45 (0.42)	0.74	0.42
q	1.22 (1.09)	3.16 (2.73)	0.59 (0.66)	2.73	0.66
CPR (TDM)	1.15	1.62	0.83		
CPR (light)	1.23	1.92	0.78		
CPR (water)	1.03	1.36	0.94		

overall transpiration by the intercrop was similar to the expected value. On average, over both periods of measurement, the value of q for sorghum in the intercrop was similar to that of the sole crop though for groundnut, both transpiration and the average value of q in the intercrop were less than expected.

DISCUSSION

In this experiment, the CPR for total dry weight was 1.08 and the comparable LER was 1.06 (Table 1). Thus, whichever index is chosen, there was little increase in the *overall* productivity of the intercrop compared with the combined sole crops.

However, there were differences in the *reproductive yields* of the two systems. Furthermore, there were clear differences between the two methods of calculating the intercrop yield advantage; the CPR for reproductive weight was 1.27 whereas the comparable LER was only 1.09. This apparent discrepancy occurs because the two indices are not synonymous. The LER indicates that 9% more land would have been required under sole cropping to produce *exactly* the same yields of the two components of the intercrop. In contrast, the CPR shows that 27% more total yield was achieved by the intercrop when compared with *exactly* the same area under sole crops sown in the same proportions as the intercrop. The concept of CPR is therefore appropriate for situations where we require a common 'currency' to assess the relative importance of individual resources to the final advantage of an intercrop, either for each species or for the combined intercrop. The concept of an LER remains appropriate when we wish to compare the agronomic performance of an intercrop with that of each component species grown as a sole crop.

In this experiment the CPR for reproductive yield was consistent with the intercropping advantages reported for other sorghum/groundnut intercrops (Evans, 1960; Rao and Willey, 1980; Tarhalkar and Rao, 1981; Harris *et al.*, 1987). This improvement in yield reflects a reduced intra-specific competition between sorghum plants in the intercrop because individual plants were able to allocate more of their total dry matter to yield than in a sole crop. Harris *et al.* (1987) observed a similar increase in the partitioning of dry matter to reproductive structures in the sorghum component of a sorghum/groundnut intercrop grown at ICRISAT. They also noted a 6% increase in the total dry matter and a 79% increase in the pod yield of the groundnut component of the intercrop compared with its sole crop. In contrast, our study showed that competition from sorghum reduced the total dry weight of groundnut by about 12% and the comparable pod yield by about 16%. This reduction in yield is less than those reported by John *et al.* (1943) and Bodade (1964) who observed reductions of up to 50%. The reason for these large variations in relative yield between experiments may be associated with varietal differences or with the planting arrangements used. For example, in our experiment, sorghum and groundnut were sown in a 1:3 row arrangement, whereas Harris *et al.* (1987) sowed the same combination of species in a 1:2 arrangement. Differences may be related to the degree of drought experienced during the season. Although increased drought causes a reduction in the absolute yield of an intercrop it often increases the relative advantage of the intercrop compared with the sole crops (Harris *et al.*, 1987). Thus, severe stress may lead to the greatest intercropping advantage. However, such relative advantages should be treated with caution as they are often based on trivial differences in the absolute yield of plants which are suffering from severe drought. Thus, assessments of CPR or LER should always include the absolute yields from which they are calculated.

An increase in the productivity of an intercrop can be ascribed either to a spatial advantage before the removal of the first species or to a temporal advantage between the removal of the first species and harvest of the second.

In this experiment the CPR for total dry weight at the removal of sorghum was equivalent to that at final harvest (Fig. 1). However, in terms of reproductive yield, the CPR at the final harvest of sorghum (103 DAS) was 1.77 whereas that at the final harvest of groundnut was 1.27.

To produce this increase in yield there must have been a spatial advantage in the capture and/or use of resources. By the final harvest of sorghum, the intercrop had intercepted 22% more radiation than the combined sole crops (Table 2). However, the conversion coefficient, e, of this radiation was less for both the sorghum and groundnut components than in the comparable sole crops and hence the lower than expected advantage in total productivity.

Before the removal of the sorghum, total evaporation from the intercrop was similar to that from the combined sole crops. As there was only a small difference between the intercrop and combined sole crops in the total dry matter accumulated over this period, the overall value of q remained fairly constant Thus, the total evaporation and dry matter production of the intercrop suggest that there was little change in the amount of water extracted or the value of q for each species in the intercrop compared with its sole counterpart. However there were clear differences in the amount of water extracted by each species (Table 2). For both periods (50-77 DAS and 83-103 DAS), sorghum in the intercrop extracted substantially more water than expected but its average value of q was similar to that of its comparable sole crop. In contrast, groundnut in the intercrop extracted less water than expected and its average value of q was also less than that of the sole crop. The increased extraction of water by sorghum in the intercrop might be explained by the greater competitive ability of its root system compared with groundnut, both in terms of the rate of descent and final depth of roots. Variations in the value of q may be explained by fluctuations in the saturation deficit (SD) experienced by each species in the intercrop and sole crops because, for any species, q is inversely proportional to SD (Monteith, 1986). However, the relatively slow rates of growth and transpiration in each species, in response to increasing water deficits meant that absolute values during the periods of measurement were small and therefore relative differences should be treated with caution. Further investigations are required, both in stressed and irrigated environments, to provide more direct measurements of differences in resource capture and use by intercrops and their component species.

REFERENCES

Ahmed, S. & Rao, M. R. (1982). Performance of maize-soybean intercrop combination in the tropics Results of multilocation study. *Field Crops Research* 5:147-161.

Azam-Ali, S. N. (1983). Seasonal estimates of transpiration from a millet crop using a porometer. *Agricultural Meteorology* 30:13-24.

Azam-Ali, S. N. (1984). Environmental and physiological control of transpiration by groundnut crops *Agricultural and Forestry Meteorology* 33:129-140.

Bodade, V. N. 1964. Mixed cropping of groundnuts and jowar. *Indian Oilseeds Journal* 8:297-301.

Doyle, A. D. & Fischer, R. A. (1979). Dry matter accumulation and water use relationships in whea crops. *Australian Journal of Agricultural Research* 30:815-829.

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

Francis, C. A. (1986). Distribution and importance of multiple cropping. 1-20. In *Multiple Cropping Systems.* (Ed. by C. A. Francis). New York: Macmillan.

Francis, C. A., Flor, C. A. & Temple, S. R. (1976). Adapting varieties for intercropped systems in the tropics. In *Multiple Cropping.* American Society of Agronomy Special Publication No. 27, 235-253 (Eds R. I. Papendick, P. A. Sanchez and G. B. Triplett). Madison, Wisconsin: American Society of Agronomy.

Harris, D., Natarajan, M. & Willey, R. W. (1987). Physiological basis for yield advantage in a sorghum/groundnut intercrop exposed to drought. 1. Dry-matter production, yield and light interception. *Field Crops Research* 17:259-272.

John, C. M., Seshadri, C. R. & Bhavani Shanker Rao, M. (1943). Mixed cropping of groundnuts. *Madras Agricultural Journal* 31:191-200.

Marshall, B. & Willey, R. W. (1983). Radiation interception and growth in an intercrop of pearl millet/groundnut. *Field Crops Research* 7:141-158.

Monteith, J. L. (1977). Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society*, London Series B, 281:277-294.

Monteith, J. L. (1986). How do crops manipulate water supply and demand? *Philosophical Transactions of the Royal Society*, London Series A 316:245-259.

Ong, C. K. & Monteith, J. L. (1984). Response of pearl millet to light and temperature. In *Agrometeorology of Sorghum and Millet in the Semi-Arid Tropics: Proceedings of the International Symposium, 15-20 November 1982, ICRISAT Center, India.* Patancheru, India: ICRISAT.

Rao, N. G. P., Rana, B. S. & Tarhalkar, P. P. (1980). Stability, productivity, and profitability of some intercropping systems in dryland agriculture. In *Proceedings International Workshop on Intercropping,* 10-13 January 1979, ICRISAT, Patancheru, Andhra Pradesh, India, 292-305. Patancheru, India: ICRISAT.

Rao, M. R. & Willey, R. W. (1980). Current status of intercropping research and some suggested experimental approaches. In *Proceedings, Second Review Meeting INPUTS Project Honolulu, Hawaii, May 8-19, 1978.*

Reddy, M. S., Floyd, C. N. & Willey, R. W. (1980). Groundnut in intercropping systems. In *Proceedings of the International Workshop on Groundnuts,* 13-17 October, 1980, Patancheru, Andhra Pradesh, India.

Sivakumar, M. V. K. & Virmani, S. M. (1980). Growth and resource use of maize, pigeonpea and maize/pigeonpea intercrop in an operational research watershed. *Experimental Agriculture* 16:377-386.

Stewart, J. I., Misra, R. D., Pruitt, W. O. & Hagan, R. M. (1975). Irrigating corn and grain sorghum with a deficient water supply. *Transactions of the American Society of Agricultural Engineers* 18:270-281.

Tarhalkar, P. P. & Rao, N. G. P. (1981). Genotype-plant density considerations in the development of an efficient intercropping system for sorghum. In *Proceedings of the International Workshop on Groundnuts,* 13-17 October, 1980, Patancheru, Andhra Pradesh, India, 35-40.

Wahua, T. A. T. & Miller, D. A. (1978). Relative yield totals and yield components of intercropped sorghum and soybeans. *Agronomy Journal* 70:287-291.

Wein, H. C. & Smithson, J. B. (1979). The evaluation of genotypes for intercropping. In *Proceedings International Workshop on Intercropping, 10-13 January 1979, ICRISAT, Patancheru, Andhra Pradesh, India,* 105-116.

Willey, R. W. (1979). Intercropping - its importance and research needs. 1. Competition and yield advantages. *Field Crop Abstracts* 32:1-10.

Willey, R. W. & Rao, M. R. (1981). Genotype studies at ICRISAT. In *Proceedings International Workshop on Intercropping, 10-13 January 1979, ICRISAT, Patancheru, Andhra Pradesh, India,* 117-127.

Willey, R. W. & Osiru, D. S. O. (1972). Studies of mixtures of maize and bean (*Phaseolus vulgaris*) with particular reference to plant population. *Journal of Agricultural Science*, Cambridge 79:517-529.

Willey, R. W. (1985). Evaluation and presentation of intercropping advantages. *Experimental Agriculture* 21:119-133.