Elsevier Science Publishers B.V., Amsterdam

The microclimate and productivity of a groundnut/millet intercrop during the rainy season*

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(Received 13 June 1990; revision accepted 29 January 1991)

ABSTRACT

Ong, C.K., Subrahmanyam, P. and Khan, A.A.H., 1991. The microclimate and productivity of a groundnut/millet intercrop during the rainy season. Agric. For. Meteorol., 56: 49–66.

The microclimate of a pearl millet/groundnut intercrop (1:3 row arrangement) was monitored for three successive rainy seasons, 1985–1987, at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India. The main objective was to quantify the changes in microclimate in intercrop and to relate these changes to the performance of the component crops in terms of growth and yield.

Major changes in microclimate of intercrop were in the wind speed and the relative duration of leaf wetness. Reduction in wind speed just above the groundnut crop was dependent on the height of the pearl millet canopy. Wind speed was reduced by 50% at 35 days after sowing (DAS) in 1985 and by 70% at 60 DAS in 1987. Leaf wetness duration of the groundnut was increased by intercropping but this appeared to have little effect on defoliation. The effect of temperature on crop development was estimated by calculating thermal time. This showed that the intercropped groundnut developed 2.5–2.8 days earlier than sole groundnut. The effect of saturation deficit on crop growth was small. Intercropping increased the radiation use efficiency of groundnut by 21–35%.

Yield loss from foliar diseases of groundnut was 37–40% in 1985, negligible in 1986 and 33–35% in 1987. However, intercropping appeared to have no significant effect on the severity of foliar disease in groundnut, largely because defoliation occurred after the pearl millet was harvested. Therefore the grain yield of intercrop sprayed with fungicide was similar to that of the unsprayed control. The land equivalent ratio of the intercrop ranged from 1.67 in 1985 to 0.94 in 1987. The discussion highlights differences between observations made during the rainy and post-rainy seasons.

INTRODUCTION

Current interest in the investigation of the microclimate of intercropping is largely the result of the realisation that further progress based on agronomic research, e.g. involving combinations of species, population and fertilisers, is

*Submitted as ICRISAT Journal Article No. 1065.

0168-1923/91/$03.50

limited because it is unreliable to generalise from experience at one site. In addition, a better understanding of microclimate of intercrop is necessary to explain why the performance in sole crop is not sufficient to fully explain the performance in intercrop.

The microclimate of an intercrop is modified when there is a large overlap in the period of active growth of both crops. For example, in a groundnut/pearl millet intercrop of 80/105 days durations, the onset of linear growth rate is between 35–40 days for both crops and the overlap lasts 40 days. The development of leaf area index (LAI) is also very similar for both crops peaking at 50–55 days (Reddy and Willey, 1981). In such a system the above-ground interaction is likely to be complex resulting in changes in the properties of the canopy for intercepting rain and light and also as a shelter for pests and pathogens. However, a system with a wide difference in crop duration, e.g. a sorghum/pigeonpea intercrop 90/170 days experiences very small above-ground interactions as pigeonpea flowers at 120 days, well after the sorghum has been harvested. Consequently the microclimate of the former system has received more attention than the latter (Marshall and Willey, 1983).

Recent investigations of the microclimate of groundnut/millet intercrop or similar systems have concentrated on the effects of water stress (Natarajan and Willey, 1986; Harris et al., 1987). These experiments were carried out during the post-rainy season when the air was much drier than during the rainy season (typical saturation deficits of 2.8 kPa compared to 1.4 kPa), even in drought years (Monteith, 1986). Because the air was dry the leaves were wet only for brief periods during irrigation or when dew occurred.

As intercropping is practised almost exclusively during the rainy season there is an urgent need to assess the microclimatic modification during the rainy season. In wet years a major microclimatic modification may be the extent and duration of leaf wetness, which affect foliar diseases on groundnut and can result in yield loss of 30–70% (ICRISAT, 1986). In dry years, the beneficial effect of shade in reducing radiation load on the groundnut intercrop may be more important. Consequently, any attempt to determine the importance of changes in microclimate in intercrop should separate the indirect influence of foliar diseases from direct effects on growth.

This paper describes measurements made on a millet/groundnut intercrop over three successive rainy seasons at Hyderabad, Peninsular India, in an attempt to determine the changes in microclimate and the consequences on the growth and productivity of the component species. A follow up paper will examine the influence of microclimate on disease development.

MATERIALS AND METHODS

Experimental conditions

The study area was on an Alfisol at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, (18°N, 78°E, 545 m above sea level). Sole stands of pearl millet (*Pennisetum glaucum* S&M cv. BK 560) and groundnut (*Arachis hypogaea* L. cv. Kadiri 3, formerly Robut 33-1) were sown in rows which were 30 cm apart between the end of June and the first week of July, as the monsoon rain allowed. The crops were thinned 3 weeks after sowing to leave groundnut plants spaced at 10 cm intervals within rows, giving a population of 33.3 plants m^{-2} and pearl millet spaced at 15 cm intervals (22.2 plants m^{-2}). The intercrop consisted of three rows of groundnut to every row of pearl millet and the intra-row spacing was identical to that of the sole crops. All crops received a basal dressing of 46 kg ha^{-1} P (as P_2O_5) and 16 kg ha^{-1} N, the sole pearl millet plants were top dressed with 80 kg ha^{-1} N (as urea) and the millet intercrop received 20 kg ha^{-1} N or one quarter of the sole millet dressing. Standard weeding was carried out in all crops at 20 and 50 days after sowing (DAS). The experiment was laid out in a randomised block design with three replications and five treatments. Two additional treatments were carried out on sole groundnut and intercrop which were sprayed every 10 days with Daconil^{R} (1.7 kg in 500 l of water ha^{-1}) to control leaf spots (*Cercospora arachidicola* Hori and *Phaeoisariopsis personata*, (Berk. & Curt.) v. Arx) and rust (*Puccinia arachidis* Speg.) in groundnut. Each plot was 15 × 30 m and the rows were arranged in an east–west direction. Details of the experiments are given in Table 1. In 1985, the total rainfall during the experiment was 371 mm with 100 mm after the harvest of millet but in 1986 there was no rainfall after the millet harvest. Rainfall in 1987 was well distributed with a total of 582 mm during the whole experiment (Table 1).

Measurements

Measurements of microclimate were restricted to one plot each of the sole pearl millet, sole groundnut and unsprayed intercrop. Wind speed, saturation deficit and air temperature were measured at three heights (0.3 m, 0.9 m and 1.2 m) with sensors mounted on single masts in each crop (see Table 2 for details of instruments used). In addition leaf temperatures and leaf wetness were measured at the top and bottom of each canopy. Leaf temperatures were measured using thermocouples and an infra-red thermometer. Leaf wetness was detected from the impedance change of a grid sensor. This was calibrated to give percentage leaf wetness by covering the grid with moist filter paper. Soil temperature was measured at a depth of 5 cm beneath the crop row. Sig-

TABLE 1

Summary of experimental conditions and treatments

Sowing dates	:	27 June 1985 8 July 1986 1 July 1987
Soil	:	Medium deep Alfisols
Design	:	Randomised block design, 3 replications
Plot size	:	15×30 m
Treatments	:	Sole pearl millet cv. BK-560 Sole groundnut cv. Kadiri-3 Sole groundnut, sprayed Intercrop 1:3 millet/groundnut Intercrop 1:3 millet/groundnut sprayed
Rainfall	:	1985 0–80 DAS 273 mm 0–115 DAS 371 mm 1986 0–80 DAS 419 mm 0–110 DAS 419 mm 1987 0–80 DAS 301 mm 0–115 DAS 582 mm

TABLE 2

Instruments for microclimate measurements

Variable	Instrument	Positioning
Wind speed	Met-One (Model 014A) Anemometer	30, 90 cm 1.5 m
Saturation deficit	Aspirated psychrometer (Ong, 1989)	30, 90 cm 1.5 m
Air temperature	Aspirated psychrometer (Ong, 1989)	30, 90 cm 1.5 m
Leaf temperature	T-type (copper–constantan, 0.19 diameter) thermocouple	30, 90 cm 1.5 m
Soil temperature	T-type (copper–constantan, 0.56 mm diameter) thermocouple	5 cm depth
Leaf wetness	Campbell (Model 237)	Top and bottom of groundnut canopy
Intercepted radiation	Prototype integrating quantum sensor Matthews et al. (1986)	2, 30 cm

nals from all instruments were monitored every 6 min with a data logger (21X Campbell) which computed and stored hourly averages. Light interception was measured at 2 and 30 cm in 1985 and 1986 but only at 2 cm in 1987. Measurements were made at mid-day once a week using a travelling quantum sensor as described by Matthews et al. (1986).

Plants were harvested for growth analysis at weekly intervals, from 21 DAS until maturity. At each harvest, all above ground material (including peg and pod) was collected from four 1-m row lengths of each treatment. In the intercrop, three rows of groundnut and one row of millet were harvested. The material was separated into leaves, stems, pegs, pods and panicles. Leaf area was measured with a LICOR areameter and then all material was dried at 70°C to constant weight. When the crops reached maturity an area of 4 m^2 was harvested from each plot and the total shoot and grain yield were weighed. A sub-sample was taken to determine moisture content to calculate total dry matter production and dry grain weight.

RESULTS

Canopy development and dry matter production

There were huge differences in the canopy development of the sole crops between the three rainy seasons (Figs. 1a and 2a). The pearl millet grew fastest in 1985 and LAI reached a maximum of 3.5. The maximum LAI was only 1.5 in 1986 and was low early in 1987, largely owing to infestation by caterpillars. Regrowth by tillers led to an increase in LAI late in the 1987 season. The trend of total dry matter accumulation of millet also reflected the differences in the rate of canopy formation between the three seasons (Fig. 1b). The onset of rapid panicle growth was earliest in 1985 (45 DAS) and latest in 1987 (51 DAS). However grain yield at maturity was in reverse order i.e. 1987 > 1986 > 1985 which reflected the total amount of rainfall received during grain-filling (Table 1).

Canopy development of sole groundnut was also considerably different in the three seasons, and LAI in the 1987 season was intermediate between the 1985 and 1986 season. A severe infestation of leaf miner in 1987 affected the groundnut crop from 50 DAS but the decline in LAI was similar to that in 1985. In 1986 a long period of drought, 60–100 DAS maintained the LAI at only half the value of other years and growth was negligible during most of that period (Fig. 2). The pattern of canopy development and dry matter production of intercropped groundnut displayed the same trend as that of sole groundnut (Figs. 3a and b).

Comparison of the LAI of the sprayed and unsprayed groundnut in both sole and intercrop indicated that reduction in LAI by foliar diseases appeared just before or after the maturity (80 DAS) of pearl millet in 1985 and 1987.

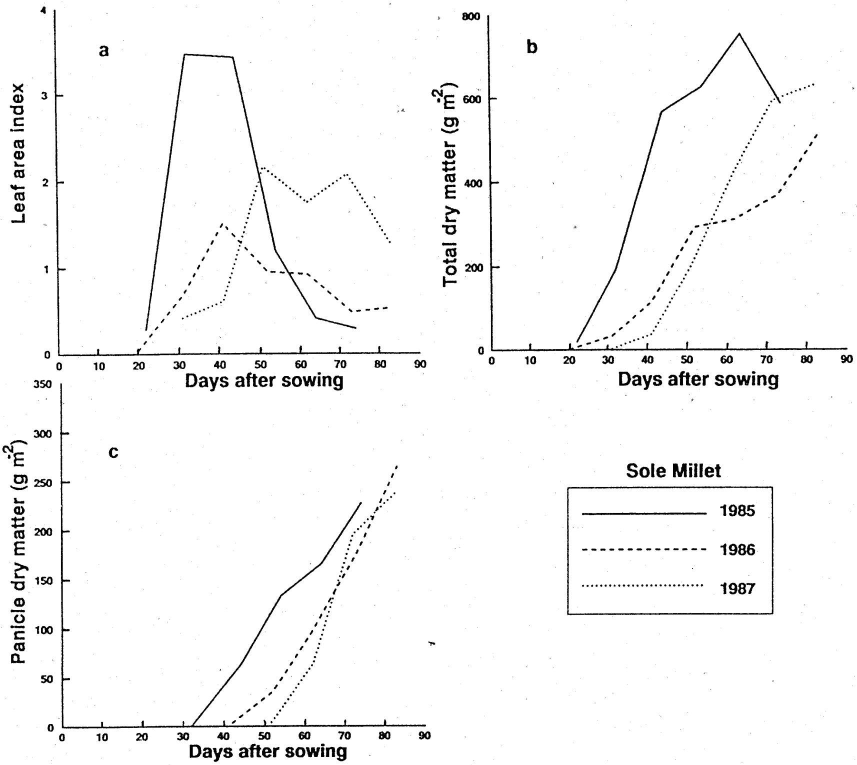

Fig. 1. Comparison of the seasonal trend in leaf area index (a), total dry matter production (b) and panicle dry matter (c) of pearl millet, rainy seasons, 1985–1987.

In 1986 there was no difference in LAI owing to fungicide treatment because of the long drought period. In other years fungicide treatment reduced the rate of decline of LAI so that towards crop maturity the LAI of sprayed groundnut was about 1.6 fold greater than unsprayed in both sole and intercrop in 1985; in 1987, final LAI for sprayed groundnut was 2.3 fold greater in sole treatment and 2.5 fold greater in intercrop. Thus even when defoliation was severe, intercropping had little effect on the amount of defoliation.

The performance of the sole pearl millet, sole groundnut and the intercrops was examined in terms of the total amount of radiation intercepted by the foliage and the conversion efficiency, *e*, expressed as g of dry matter produced MJ^{-1} of intercepted radiation. In all years the sole millet had intercepted more radiation than the sole groundnut or the intercrop by 80 DAS (Table 3). This observation is consistent with the faster rate of canopy formation and the higher LAI achieved by the millet (Fig. 1a). After the millet was harvested, interception by the intercropped groundnut declined, largely as a result of a

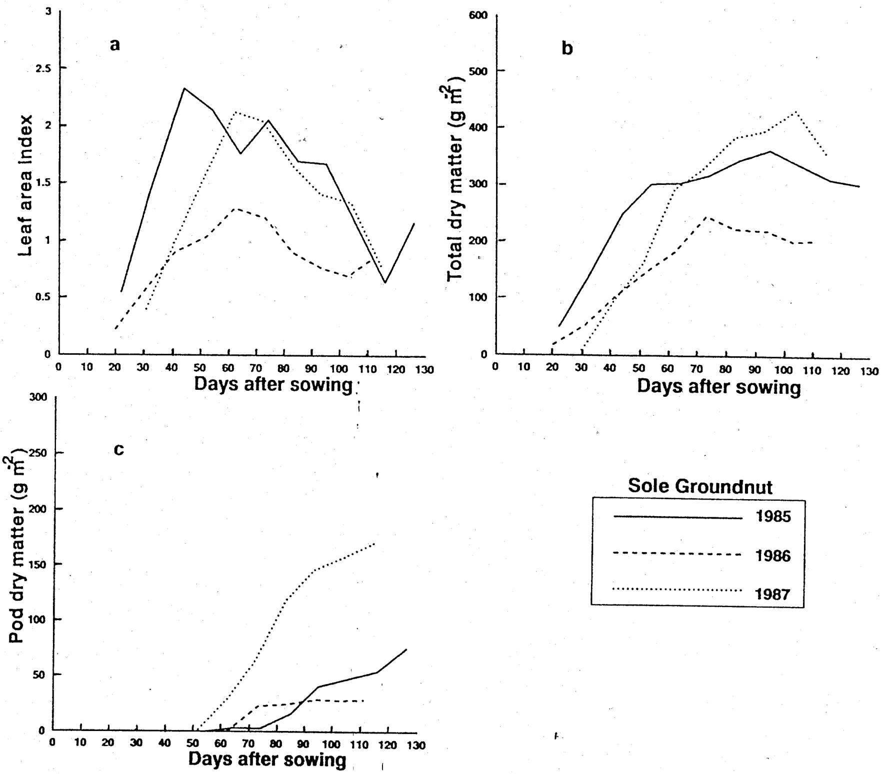

Fig. 2. Comparison of the seasonal trend in leaf area index (a), total dry matter production (b), and pod dry matter (c) of groundnut, rainy season, 1985–1987.

reduction in LAI. However, the radiation intercepted by the intercropped groundnut was more than expected from the proportion of plants (0.75 of sole) compared with sole groundnut. In 1985 and 1987 the intercropped groundnut intercepted 20 to 27% more radiation than expected during the period 80 DAS to maturity. In the driest year 1986, intercropped groundnut intercepted 52% more than expected.

Intercropping improved *e*, compared with sole groundnut, from 20 to 80 DAS in all 3 years. Analysis of the fraction of radiation intercepted by each intercrop component was possible in 1985 and 1986 when the radiation above the groundnut was measured separately. The improvement in *e* of the intercrop was greatest in 1985 when *e* was 0.73 g MJ^{-1} compared with 0.54 g MJ^{-1} in sole groundnut. In 1986, *e* from 35 to 80 DAS of intercropped groundnut increased from 0.60 to 0.68 g MJ^{-1}. For the intercrop millet, *e* was unchanged. The highest value of *e* occurred in 1987 when rainfall was highest, indicating that in the absence of water stress the maximum values of *e* for

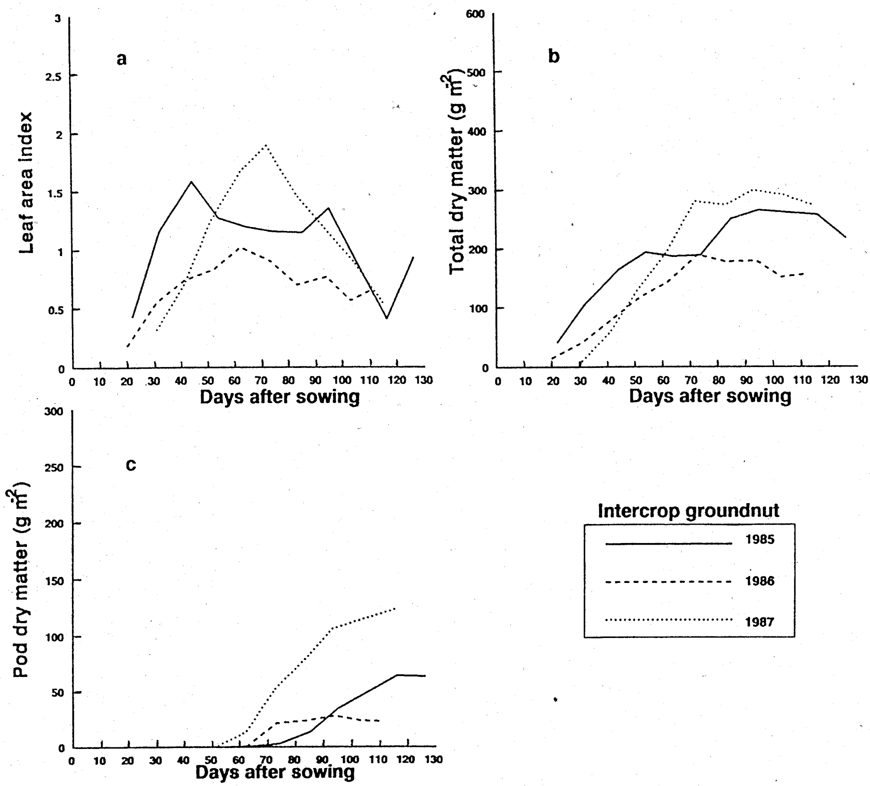

Fig. 3. Comparison of the seasonal trend in leaf area index (a) total dry matter (b) and pod dry matter (c) of intercrop groundnut, rainy seasons, 1985–1987.

pearl millet and groundnut were 1.29 g MJ^{-1} and 1.14 g MJ^{-1}, respectively. The efficiency of radiation conversion fell substantially from 80 DAS to maturity, especially in 1986 when drought was most severe. Even in the wettest year, 1987, *e* was only 0.10–0.19 g MJ^{-1}, indicating that there was a major reduction in the photosynthetic rate of the canopy. As most of the carbohydrate produced was converted into proteins and fats for kernal growth, the value of *e* in terms of carbohydrate was 1.65 times greater i.e. 0.33 g MJ^{-1} in the sole groundnut in 1987. This value is still only one third of that occurring before 80 DAS.

The interactions between the component crops in intercropping can be analysed in terms of the land equivalent ratio (LER), which is defined as the proportional total area of sole crops required to produce the same yield as achieved in the intercrop (Willey, 1979). In 1985, LER was highest for total biomass and grain yield in the unsprayed control (1.34 and 1.57 respectively,

TABLE 3

Comparison of canopy performance of pearl millet, groundnut and pearl millet/groundnut intercrop grown on an Alfisol, rainy seasons 1985–1987

Year	Crop	Mean irradiance (MJm^{-2} day^{-1})	Total radiation intercepted (MJm^{-2})		Efficiency of radiation conversion ($g\ MJ^{-1}$)	
			20–80 DAS	80–Maturity[1]	20–80 DAS	80–Maturity[1]
1985	Pearl millet	16.6	584	–	0.92	–
	Groundnut	17.3	453	319	0.54	0.13
	Pearl millet/groundnut	17.3	512	287	0.73	0.06
1986	Pearl millet	18.5	565	–	0.89	–
	Groundnut	18.5	348	125	0.60	0.03
	Pearl millet/groundnut	18.5	385	143	0.68	0.04
1987	Pearl millet	16.2	442	–	1.29	–
	Groundnut	14.3	310	246	1.07	0.19
	Pearl millet/groundnut	14.3	378	236	1.14	0.10

[1] Values for groundnut only.

TABLE 4

Mean dry matter and yield ($t\ ha^{-1}$) of all crops and the LER of intercrop for three rainy seasons

Year	Crop	Total dry matter	LER_1	Pod or grain yield	LER_2
1985	Pearl millet	6.10	–	1.23	–
	Groundnut	2.80	–	0.93	–
	Groundnut sprayed	4.05	–	1.48	–
	Intercrop	3.00/2.38[1]	1.34	0.85/0.82[1]	1.57
	Intercrop sprayed	3.20/3.63[1]	1.42	0.92/1.36[1]	1.67
1986	Pearl millet	4.72	–	1.81	–
	Groundnut	2.10	–	0.16	–
	Groundnut sprayed	2.51	–	0.21	–
	Intercrop	2.27/1.65[1]	1.26	1.04/0.05[1]	0.88
	Intercrop sprayed	1.76/2.06[1]	1.19	0.80/0.20[1]	1.39
1987	Pearl millet	6.47	–	2.21	–
	Groundnut	3.60	–	1.89	–
	Groundnut sprayed	5.55	–	2.80	–
	Intercrop	2.29/2.63[1]	1.08	0.87/1.25[1]	1.05
	Intercrop sprayed	2.35/3.64[1]	1.02	0.81/1.60[1]	0.94

[1] Values for millet/groundnut.
LER_1, based on total dry matter; LER_2, based on grain or pod yield.

Table 4). In the same year losses in groundnut yield from foliar disease were 37% in sole crop and 40% in intercrop compared with sprayed treatments.

In 1986, LER for biomass was lower than the previous year and pod yield was extremely low. This was probably related to the prolonged period of drought. With such low yields it would be unrealistic to attach much significance to the value of LER, which ranged from 0.88 to 1.39.

Foliar disease caused a major reduction in groundnut biomass (35%) and pod yield (33%) in 1987. However, there was no evidence from the small values of LER of both sprayed and unsprayed treatments, that intercropping had an appreciable effect on the severity of foliar disease or the foliar disease had an appreciable effect on LER. In addition there was no appreciable difference in LER for both biomass and pod yield.

Changes in microclimate of groundnut

Wind speed

The major changes in microclimate experienced by the intercropped groundnut were in the wind speed and percentage leaf wetness as the pearl millet grew taller, reached a peak at 45 DAS and declined as leaf senescence and abscision commenced (Figs. 4 and 5). In 1985, the faster growth of the

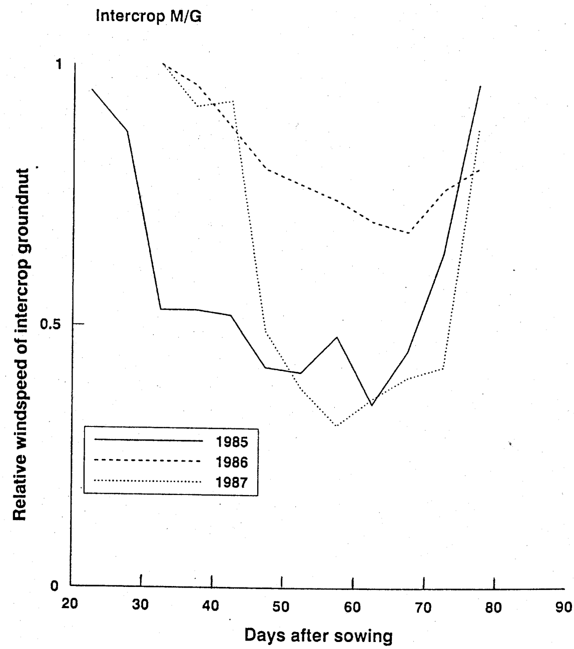

Fig. 4. Relative wind speed of intercrop groundnut in 1985–1987.

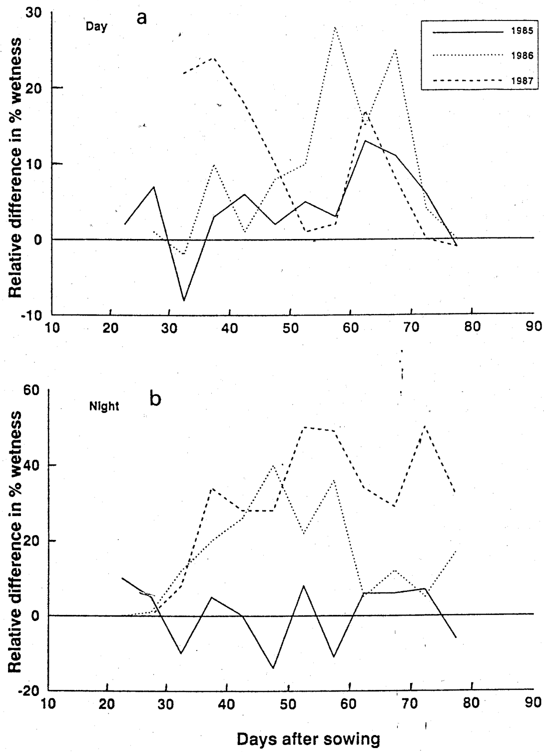

Fig. 5. Relative difference in percent leaf wetness during the day, 06:00–18:00 h (a) and night, 18:00–06:00 h of intercrop groundnut, 1985–1987.

pearl millet resulted in a substantial reduction (50%) in wind speed by 35 DAS which was maintained until 75 DAS. In 1986, when millet growth was exceptionally poor, the maximum reduction in wind speed was only 30% and the changes in wind speed started after 40 DAS. In 1987, the significant reduction in wind speed occurred much later (40 DAS) than in 1985, and reached a maximum of 70% at 60 DAS. Mean wind speed during the growth of pearl millet (20–80 DAS) ranged from 2.2 to 2.6 m s^{-1} (at the height of groundnut crop) and the total reduction in wind speed recorded at the intercrop was 32–44%. A much larger reduction in wind speed would be achieved if the rows were arranged at right angles to the prevailing south-westerly winds. The orientation of the rows was in an east-west direction for all crops to facilitate drainage.

Leaf percentage wetness

The influence of intercropping on leaf wetness of groundnut is examined in terms of the percentage leaf wetness during the day (06:00–18:00 h) and night (18:00–06:00 h), and by the duration of wetness for each day. Average values for each 5 day period were calculated during the period when the two crops were together, i.e. 20–80 DAS and after the removal of pearl millet (80 DAS–maturity).

In all three seasons, the leaves of intercropped groundnut were usually wetter than the sole groundnut (Fig. 5). The greatest difference in daytime wetness occurred during the period 50–80 DAS in 1986, while in other years there was only 2–20% difference. The smallest difference in wetness occurred in 1985 when rainfall from 30–70 DAS was only 64 mm, averaging only 30% of open pan evaporation. During the night the difference between intercropped and sole groundnut was greater than during the day. Once the pearl millet was harvested there was a negligible difference in wetness between the intercropped and sole groundnut. In 1985 and 1987 there was only a small difference in the percentage wetness during the day and night for the period of 80 DAS–maturity even though the differences in rainfall received was 100 mm in 1985 and 282 mm in 1987.

Duration of leaf wetness

The duration (h) of leaf wetness for each day is calculated as the period when percentage wetness exceeded 20% or 40% for the period 30–80 DAS and 80 DAS–maturity. In 1985, intercropping increased the average duration of wetness by 0.6 to 2.7 h although most of the rain fell before the millet was tall enough to modify the microclimate (Table 5). In contrast, intercropping in 1986 and 1987 had marked effect on the duration of leaf wetness which in 1986 increased from 9 to 16 h day^{-1} at 20% wetness and from 6 to 14.6 h day^{-1} at 40% wetness. An analysis of the rainfall events from 30–80 DAS

TABLE 5

Comparison of the duration of leaf wetness in sole and intercrop groundnut, 1985–1987

Year	Rainfall (mm)	Duration (h day^{-1})			
		>20% wetness		>40% wetness	
		Sole	Intercrop	Sole	Intercrop
30–80 DAS					
1985	208	3.9	4.2	2.6	3.2
1986	190	9.0	16.3	6.3	14.6
1987	165	8.7	13.6	8.3	11.8
80 DAS–maturity					
1985	128	14.1	17.0	12.0	13.2
1986	0	2.6	1.0	0.7	0.7
1987	149	12.7	15.6	10.6	13.5

showed that 20 of the 23 rainfall events were less than 10 mm and intercropping prolonged the duration of each wetness period by 1–3 h.

In the wet period 32–40 DAS of 1986, intercropping increased the daily duration of wetness (>40%) from 12.7 to 19.2 h. With large storms (>30 mm rainfall per event) both cropping systems were wetted to a similar degree but the difference in wetness duration was more substantial on the following day. However, large storms were relatively rare in all three seasons. As expected, there was little difference in duration of leaf wetness between the sole and intercropped groundnut after harvest of the pearl millet. The duration was least in 1986 when there was little disease and the other years, when foliar disease reduced yield by 33 to 40% (Table 5) were quite similar.

Temperature

The response of groundnut to temperature is well established, the main effect being on the rate of plant development, i.e. time to flowering, leaf production and duration of reproductive period (Leong and Ong, 1983). Soil temperature is important during seedling growth and for the development of pegs and pods. In order to quantify the effect of temperature it is appropriate to calculate the thermal time θ, from hourly temperature using the equation

$$\theta = t_1(T_1 - T_b) + t_2(T_m - T_2)K$$

(Garcia-Huidobro et al., 1982) where t_1 is the period when the temperature T_1 is below the optimum temperature $T_o = 36.5°C$ but above the base $T_b = 10°C$ and t_2 is the period when temperature T_2 is between T_o and the maximum $T_m = 46°C$ (Mohammed et al., 1988). K is the constant describing

TABLE 6

Comparison of mean soil and leaf temperature and accumulated thermal time from 21 to 80 DAS of sole crops and intercrop, 1985–1987

Year	Parameter	Mean temperature (°C)			Thermal time (degree day)		
		Millet	Groundnut	Intercrop	Millet	Groundnut	Intercrop
1985	Soil	27.8	27.6	27.6	1050	1037	1041
	Leaf top	27.0	26.7	27.1	1003	984	1010
	Leaf bottom	27.2	26.9	27.4	1017	1001	1026
1986	Soil	27.5	27.3	28.2	1030	1023	1074
	Leaf top	25.1	25.3	26.1	893	904	951
	Leaf bottom	25.8	25.8	26.2	934	934	956
1987	Soil	26.3	25.8	25.7	961	933	925
	Leaf top	25.2	24.7	24.7	899	871	870
	Leaf bottom	25.3	24.8	24.8	900	872	873

the ratio of the relationship above T_b and below T_m, K for Kadiri-3 and BK-560 is 2.76.

In all 3 years the mean soil temperature was generally 1–2°C higher than the leaf temperature (Table 6) with very small differences between the three crops. The greatest difference in accumulated thermal time between sole and intercropped groundnut was in 1986 which represented a 2.8 day difference in soil and 2.5 day difference in leaf temperature. This analysis shows that differences in temperature owing to intercropping are unlikely to have a major effect on crop development.

Saturation deficit

Saturation deficit influences the evaporation rate and plant water use efficiency, but it is a difficult quantity to relate to plant growth and development. As it influences water loss and photosynthesis the average saturation deficit is calculated for the day 06:00–18:00 h and the following equation is used to estimate its possible effects on growth

$$Z=1-[(D-D_o)/(D_m-D_o)]$$

(Monteith, 1986) where D_o is the saturation deficit below which photosynthesis is maximum and D_m is the deficit when photosynthesis is zero. For the purpose of this calculation $D_o=1$kPa, $D_m=6$ kPa and D is the daytime aver-

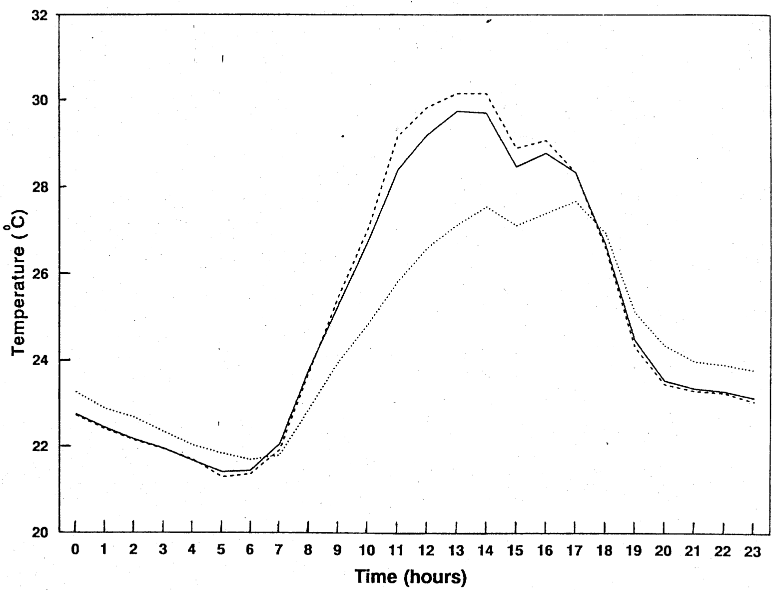

Fig. 6. Average diurnal temperature curves of air (...) and leaves of sole (—) and intercropped (- - -) groundnut for 40–50 DAS, rainy season 1987.

TABLE 7

Comparison of mean saturation deficit and saturation deficit factor (Z) from 21–80 DAS at crop height on sole crops and intercrop, 1985–1987

Year	Parameter	Sole millet	Sole groundnut	Intercrop
1985	Saturation deficit (kPa)	2.11	2.16	2.23
	Z	0.77	0.77	0.75
1986	Saturation deficit (kPa)	1.83	2.14	2.19
	Z	0.83	0.77	0.76
1987	Saturation deficit (kPa)	1.91	1.87	1.90
	Z	0.82	0.83	0.82

age saturation deficit. As leaf temperature of the sole and intercropped groundnut were consistently higher than air temperature during the day (Fig. 6) the D for leaf is calculated rather than the saturation difference between leaf and air (Table 7). Comparison of leaf temperature measurements using a thermocouple and an infra-red thermometer showed good agreement.

Mean saturation deficit during the 3 years ranged from 1.83 to 2.23 kPa (Table 7) which was within the range observed during the rainy season over the last 10 years. The cloudy conditions in 1985 and 1987 were primarily responsible for the lower saturation deficit whereas the sky was relatively clear in 1986 (Table 3). The value of Z was quite similar in all 3 years including the driest year, 1986 when the value was 0.76. Again, intercropping had negligible influence on saturation deficit or Z.

DISCUSSION

An earlier report on the overall productivity of a groundnut/millet system during the rainy season, 1978 at Hyderabad gave a LER of 1.28. This was explained by a similar increase in the efficiency of radiation conversion (Marshall and Willey, 1983). Our findings also showed an increased e of the intercropped groundnut which was 5% greater than sole groundnut in 1985 and 22% greater than sole groundnut in 1986. However, the LER for grain yield varied from 1.57 in 1985 to about 1.0 in the other two seasons. Unlike the results of 1978, the LER cannot be explained simply in terms of radiation interception and e. A comparison of the LER of the same intercrop over 6 successive rainy seasons, 1978–1983, at ICRISAT Center, showed that LER ranged from 1.21 to 1.31 when rainfall was 590–1070 mm per season (ICRISAT, 1986). The period from 1985 to 1987 represented three consecutive dry years suggesting that at low rainfall (>450 mm per season) the pattern of rainfall may be important in determing LER. Unpublished data (Ong, 1987) at ICRISAT has confirmed that the LER of a sorghum/millet intercrop varied from 1.0 to 1.8 when the timing of irrigation was changed but the total amount applied was similar.

To what extent do the present findings differ from the observations made during the post-rainy season? Virtually all workers found a substantial increase in the LER of grain yield and an increase in the harvest index of intercropped groundnut during the post-rainy season whether it was intercropped with millet or sorghum (Natarajan and Willey, 1986; Harris et al., 1987). The explanation suggested for the high partitioning to pods or grain was that cereals provided beneficial shading to the groundnut which lowered leaf temperatures of intercropped groundnut (Willey et al., 1986). There was no consistent evidence of increased harvest index of intercropped groundnut during the rainy season (Reddy and Willey, 1981; Willey and Reddy, 1981) including our present findings (except in unsprayed groundnut, Table 4). Prevention of foliar disease by fungicide application produced a 3% increase in the harvest index of the sole crop in 1985 but a 2–4% reduction in 1987. Therefore differences in groundnut between the two seasons cannot be explained in terms of foliar disease which was absent in the post-rainy trials. Instead, our evidence from 3 years is consistent with the hypothesis of Stirling (1988), that the timing of rainfall or water availability is more important in determining partitioning of dry matter than microclimate in groundnut.

The evidence that intercropping improved the radiation conversion efficiency by 21–35% of intercropped groundnut is consistent with the earlier reports by Willey et al. (1986) during the rainy season which gave a 21–23% increase. The severe drought of 1986 appeared to have some effect on the relative increase in *e* but this may be a consequence of the higher radiation which would reduce *e*. At low radiation of 8 $MJm^{-2}\ day^{-1}$, Ong et al. (1987) reported a value of 1.88 g MJ^{-1} for groundnut compared with values of 1.3 g MJ^{-1} reported by Marshall and Willey (1983) and 1.17 g MJ^{-1} by Stirling (1988) during the rainy season. Shading of groundnut crop to 50% sunlight during the rainy season increased *e* to 2.36 g MJ^{-1} (Stirling et al., 1991).

These observations imply that intercropping results obtained in the post-rainy season should be interpreted with caution especially in relation to practice during the rainy season. The beneficial effect of intercropping during the post-rainy season is only realised if irrigation is available since the crops have to depend almost entirely on stored moisture. Not surprisingly, intercropping is not practised by farmers in the post-rainy season probably because it offers little scope for reducing risks in a relatively predictable but extremely dry time of the year. In fact research at ICRISAT in 1976–1977 revealed that intercropping sorghum and chickpea, both major post-rainy crops, produced only a marginal advantage (10%) and it was not considered a worthwhile research topic (M. Natarajan, unpublished data, 1978).

Leaf wetness is expected to affect growth and yield indirectly through foliar diseases because infection by pathogens is influenced by leaf wetness (Butler, 1990). Although the extent and duration of leaf wetness were generally greater in the intercropped groundnut for all 3 years there was only a marginal influence on growth and yield. This was owing to the slow build up of foliar disease which began to have an appreciable effect on defoliation only towards the maturity of pearl millet. This suggests that leaf wetness may not be limiting disease progress and the amount of innoculum may be more important. In both 1985 and 1987, when disease was sufficient to reduce pod yield of groundnut by 33 to 40%, defoliation occurred after the harvesting of pearl millet. The influence of temperature and leaf wetness on disease development will be explored in a separate paper.

Differences in soil and leaf temperatures between intercrop and sole groundnut are unlikely to have a major effect on crop development or partitioning of dry matter to pods. Calculation of thermal time using soil or leaf temperatures showed that the maximum effect is to speed up development by only 2.5 days. Even in the post-rainy season when ambient temperature was higher the net effect on plant development was marginal (Stirling, 1988). Numerous workers have shown that the partitioning of dry matter to pods is extremely sensitive to mean temperature with a low optimum of 23°C (Ketring, 1984). Intercropping is unlikely to have a significant influence on the partitioning in groundnut via temperature modification.

Soil and leaf temperatures were remarkably similar in sole and intercropped groundnut largely because the reduction in radiation load owing to shading was presumably offset by the low wind speed in the intercrop. Corlett et al. (1989) also reached the same conclusion in a comparison of the microclimate in an alley cropping experiment with *Leucaena leucocephala* and pearl millet during the rainy season at Hyderabad. In their alley cropping system wind speed was greatly modified by the *Leucaena* hedgerow which was pruned to 0.7 m at the time of sowing of millet yet the modification of the thermal environment was relatively insignificant. Within the range of ambient temperatures experienced during the rainy season (24–26°C mean temperature) at Hyderabad it was not surprising that changes in temperature had little effect on plant development. However, if ambient temperature exceeds the optimum for several hours in the day, it is conceivable that intercropping or agroforestry might have a significant effect on plant development.

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