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GROWTH AND RESOURCE USE STUDIES IN AN INTERCROP OF PEARL MILLET/GROUNDNUT

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ABSTRACT

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Growth and resource use data are presented for the sole crops and an intercrop of an 82-day millet and 105-day groundnut. The intercrop row arrangement was 1 millet:3 groundnut and the within-row spacing of each crop was the same in sole crop and intercrop.

In groudnut, yield/plant and yield components were similar in intercropping and sole cropping. In millet, on a per plant basis the dry matter accumulation, leaf area development and tiller production were all substantially greater in intercropping compared with sole cropping; final seed yield/plant was just over twice as high in intercropping, this being achieved by increases in heads/plant and seeds/head. Calculated on the basis of a Land Equivalent Ratio (LER) intercropping gave 28% more total dry matter (LER = 1.28) and 26% more reproductive yield (LER = 1.26) than growing the two crops separately; both these yield increases were statistically significant. There were even greater increases in the total leaf area index of the combined intercrop canopy (maximum LER = 1.39) but increases in the total root length of the combined rooting system were rather smaller (maximum LER = 1.18).

The higher intercrop yield appeared to be achieved by an increased efficiency in converting light energy into dry matter and not by any increase in the amount of light energy intercepted. It is suggested that this increased efficiency may have been because the combined intercrop canopy resulted in light being more efficiently spread over a greater surface of leaf. Total water use was rather higher in intercropping and the total water use efficiency was improved because a greater proportion of the water was used by the crop rather than lost as evaporation from the soil surface. The LER values for total uptake of N, P and K in intercropping were 1.25, 1.28 and 1.26, respectively, indicating that the higher yield in intercropping was associated with a commensurately greater uptake of nutrients.

INTRODUCTION

Research during recent years has provided increasing evidence that substantial yield advantages can be achieved from intercropping compared to sole cropping. This is often attributed to the fact that different crops can 'complement' each other and make better total use of resources when growing together rather than separately. To try to obtain more information on the basis for this 'complementarity', a series of experiments was recently started at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to study the growth patterns and the resource use of selected intercrop combinations. This paper presents the first studies on pearl millet/ groundnut, an intercropping combination chosen as typical of the situation where a cereal is intercropped with a low-canopy legume. Both crops are ICRISAT 'mandate' crops and are especially important on the lighter soils of the semi-arid tropics, notably in West Africa and India.

MATERIALS AND METHODS

The experiment was carried out during the rainy season of 1978 at ICRISAT Center, which lies about 25 km north-west of Hyderabad, India (17.5°N, 78.5°E, and 545 m altitude). The experimental site was a medium deep Alfisol ('red' soil) that had an available water holding capacity of about 100 mm in the top 90 cm of the profile. Details of solar radiation, temperature and rainfall are given in Table I. Rainfall during the growing period was 932 mm which was approximately 50% above average. Waterlogging was a problem during the establishment of the crops, especially for the groundnut, but thereafter growth of both crops was good.

TABLE I

Meteorological data throughout the growing period (rainy season of 1978)

Week	Date	Average temp. Max. (°C)	Average temp. Min. (°C)	Total precipitation (mm)	Average solar radiation (ly/day)
25	18 June — 24 June	27.1	22.4	68.4	256
26	25 June — 1 July	33.0	23.0	3.4	434
27	2 July — 8 July	28.4	21.6	70.0	310
28	9 July — 15 July	28.7	21.8	56.6	389
29	16 July — 22 July	29.2	22.3	50.7	403
30	23 July — 29 July	29.5	22.7	44.7	352
31	30 July — 5 Aug.	28.8	22.2	28.0	324
32	6 Aug. — 12 Aug.	28.6	21.8	49.5	341
33	13 Aug. — 19 Aug.	26.5	21.3	300.0	266
34	20 Aug. — 26 Aug.	27.7	22.1	116.6	321
35	27 Aug. — 2 Sept.	29.3	21.3	26.2	393
36	3 Sept.— 9 Sept.	29.6	21.2	6.4	493
37	10 Sept.— 16 Sept.	29.6	21.3	38.4	458
38	17 Sept.— 23 Sept.	29.7	21.8	26.7	377
39	24 Sept.— 30 Sept.	29.6	22.0	10.0	406
40	1 Oct. — 7 Oct.	30.3	21.2	37.0	507

Treatments

Sole treatments of each crop, and an intercrop treatment of one row millet: three rows groundnut, were all grown on 30-cm rows. This particular intercrop treatment was chosen because it represents a system commonly observed in farming practice where the major area of ground is occupied by groundnut and the millet is planted quite sparsely; it had also proved a promising treatment in earlier ICRISAT studies. Within-row spacing for each crop was the same in sole crop and intercrop and was the estimated optimum spacing for the sole crop. For millet this was 15 cm, equivalent to 22.2 plants/m^2 for the sole crop. The groundnut population had to be slightly less than intended and some irregularity of stand had to be accepted because of the uneven establishment; nevertheless, population counts at the first sampling were found satisfactory with mean spacings of 14.3 cm for the sole crop (23.31 plants/m^2) and 14.0 cm for the intercrop. Treatments were laid out in four randomized blocks.

A basal fertilizer application of 50 kg/ha of P_2O_5 was applied to all plots and both crops were sown on 25 June. Sole and intercrop millet were top-dressed with N at the same rate/row, which was equivalent to 80 kg/ha in sole cropping. The millet cultivar was BK-560 which reached 50% flowering and final harvest at 50 days and 82 days after sowing, respectively, and which achieved a height of 1.8 m. The groundnut cultivar was the semi-spreading Robutt 33-1 which had a time to first flower and a final harvest of 30 days and 105 days after sowing, respectively.

Sampling procedures

Sample areas of 1.8 m^2 for the sole crops and 2.4 m^2 for the intercrop were harvested for estimation of dry matter and area of green leaf laminae at weekly intervals starting 20 days after sowing. Plants were dug up but roots were not included in the dry matter estimates (see root length estimates below).

Harvest areas of approximately 40 m^2 for sole plots and 50 m^2 for the intercrop were taken for a final estimate of total dry matter and reproductive yields. In the millet, grain yield/plant and number of heads/plant were estimated by counting plants and heads on the whole harvest area; the number of grains/head and the 1000 grain weight were estimated from a random 10 heads/plot. In the groundnut, yield per plant was based on a plant count on the whole harvest area but other components were estimated from a 1000 pod sample.

Rooting patterns were examined by coring on seven occasions in all four replicates, at weekly intervals initially and 10 day intervals later. Cores of 6.8 cm diameter were extracted with a hydraulic machine mounted on the back of a Landrover. In the sole crops, one core was taken on the row and one between the rows. In the intercrop, a transect of five cores was taken from the millet row to the middle groundnut row. Cores were cut into sections which were soaked overnight, then roots were washed out using a 0.5 mm sieve. Root length was estimated by the line intersect method of Newman (1966).

Light interception

Light interception was measured with 90-cm tube solarimeters sensitive to all solar radiation wavelengths (Szeicz et al., 1964). Crop rows were approximately N—S and all solarimeters were at right angles to these. One solarimeter/plot in sole crops and two/plot in the intercrop were placed at ground level. It was thought that growth in the groundnut rows adjacent to the millet might differ from the central groundnut rows so the two intercrop solarimeters were arranged to give equal weighting to all rows across the 1:3 pattern. Recording was carried out by attaching solarimeters to individual integrators (Times Electronics Ltd.) for 24-h periods on a 3—4 day cycle. Percent interception was calculated by comparison with a 'control' solarimeter placed above the crop and integrated continuously. Absolute incident energy was assumed to be that recorded at the nearby ICRISAT meteorological site.

Soil moisture

Soil moisture was measured by the staff of the ICRISAT Environmental Physics subprogram. Two neutron probe access tubes/sole plot and four/intercrop plot were inserted to an average depth of 140 cm. At approximately weekly intervals the moisture in the top 22.5 cm of the profile was measured gravimetrically and the lower depths were monitored with a neutron probe.

Nutrient uptake

The N, P and K contents were determined on a whole plant basis from the periodic dry matter samples. N and P were determined on an autoanalyzer by Kjeldahl and vanadomolybdate methods, respectively, and K by an atomic absorption spectrophotometer (Jackson, 1967).

RESULTS AND DISCUSSION

Sole groundnut showed a relatively slow accumulation of dry matter (Fig. 1a) but gave quite good final yields of 5617 kg/ha of dry matter and 1188 kg/ha of pods after 105 days (Table II). Sole millet showed a very rapid accumulation of dry matter (Fig. 1b) with final harvest yields of 8085 kg/ha of dry matter and 2226 kg/ha of seed after only 82 days (Table II). The dry matter accumulation of each intercrop is given in comparison with the accumulation 'expected' if yield/plant were the same in intercropping as in sole cropping; in yield/unit area terms these 'expected' yields are simply 75% of the sole groundnut yield and 25% of the sole millet yield.

TABLE II

Dry matter yields, grain and pod yields, and yield components estimated from large plots at final harvest

	Yields (kg/ha)			Yield components				
	Total dry matter	Grain or pod yield	Harvest index (%)	Pod yield/ plant (g)	No. of pods/ plant	No. of kernels/ pod	100 kernel weight (g)	Shelling out %
Sole groundnut	5617	1185	21.1	5.76	16.8	1.74	21.04	48
Intercrop groundnut	3900	840	21.5	5.73	16.1	1.72	23.02	51
LSD (0.05)	501	169	N.S.	N.S.	N.S.	N.S.	1.41	1.3
CV % (0.05)	4.68	7.41	1.23	1.28	4.09	1.33	2.85	1.17
				Grain yield/ plant (g)	No. of heads/ plant	No. of grains/ head	1000 grain weight (g)	
Sole millet	8085	2226	27.5	10.05	2.27	1396	7.04	
Intercrop millet	4775	1227	25.7	22.29	3.16	1778	6.95	
LSD (0.05)	661	46	N.S.	1.06	0.19	56	N.S.	
CV % (0.05)	4.57	1.18	1.11	2.91	3.17	1.57	1.62	

	LER	
	Total dry matter	Grain or pod yield
Groundnut	0.69	0.71
Millet	0.59	0.55
Total	1.28	1.26
LSD (0.05)	0.10	0.21
CV % (0.05)	5.41	11.24

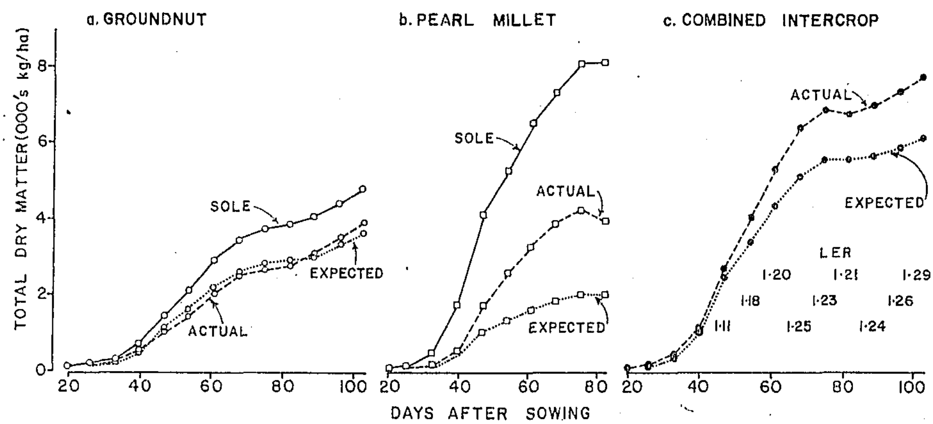

Fig. 1. Sole crop yields, and actual expected intercrop yields for groundnut and millet (see text for explanation of expected yields).

Dry matter accumulation of intercrop groundnut was roughly similar to expected, though there was some evidence of a slightly lower yield than expected prior to millet harvest (82 days) and a slightly higher one thereafter (Fig. 1a). However, this yield increase in the later stages was not reflected in any change in final pod yield/plant between intercropping and sole cropping, despite small but significant increases in shelling out percentage and 100 kernel weight (Table II). Essentially, therefore, the groundnut experienced about the same degree of competition in intercropping as in sole cropping, and thus it produced about the same yield/plant.

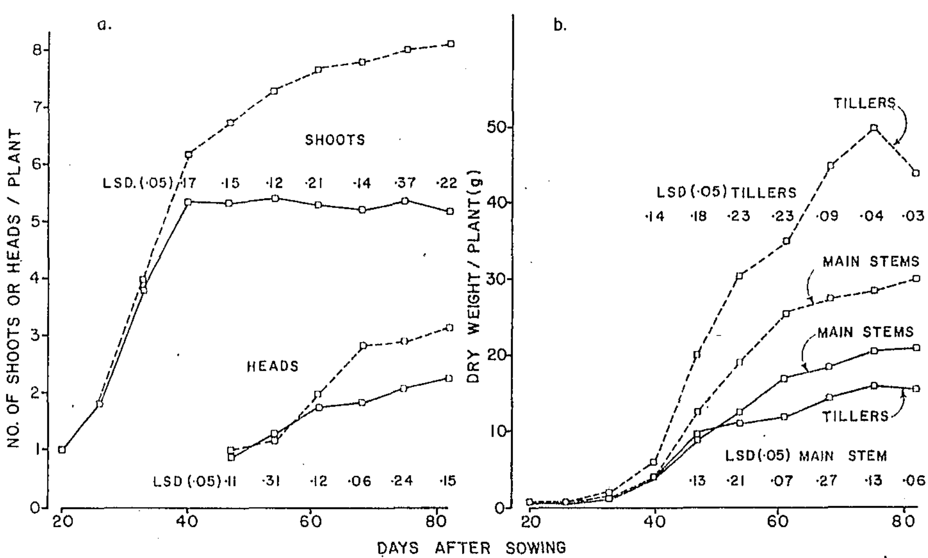

Fig. 2. Number of shoots/plant and heads/plant (a), and dry weight/plant in main stems and tillers (b), of sole (□———□) and intercrop (□···············□) pearl millet.

Dry matter accumulation of intercrop millet was much higher than expected, varying around twice the expected value of 25% of the sole crop accumulation. This was associated with the production of a greater number of shoots/plant (and eventually heads/plant) in intercropping compared with sole cropping (Fig. 2a). Total dry matter yield/plant was also much greater, partly because of more dry matter going into the main stem but principally because of more dry matter going into the tillers (Fig. 2b). The final seed yield/plant in intercropping was more than twice that in sole cropping and this could be attributed to significant increases both in number of heads/plant and number of seeds/head (Table II). In contrast to the groundnut, therefore, the millet experienced much less competition in intercropping than in sole cropping and thus it produced a much greater yield/plant.

The combined yield of both crops in intercropping is given in Fig. 1c in comparison with the yield 'expected' if intercropping achieved exactly the same yields as sole cropping. The difference between actual and expected yields illustrates the absolute yield advantage which is commonly expressed in relative terms by the Land Equivalent Ratio (LER — the relative land area that would be required as sole crops to produce the yields achieved in intercropping); in effect, the 'expected' yield is the absolute yield achieved when LER = 1. It can be seen that there was an increasing yield advantage of intercropping as the season progressed. At final harvest (Table II) the yield advantage was 28% for total dry matter (LER = 1.28) and 26% for seed and pod yields (LER = 1.26) and both these increases were statistically significant. From the effects observed on the individual crops, this advantage clearly occurred because the yield/plant of the groundnut was similar in intercropping compared with sole cropping, but yield/plant of the millet was much increased. The lack of effect on the groundnut agrees well with other cereal/groundnut experiments in which the cereal has been only a small proportion of the intercrop (Lingegouda et al., 1972 — sorghum/groundnut; Baker, 1978 — millet/groundnut) though reductions in groundnut yield have been reported where cereal proportions have been higher (Bodade, 1960 — sorghum/groundnut; Evans, 1960 — maize or sorghum/groundnut; Lingegouda et al., 1972 — sorghum/groundnut). The increases in tillering and yield/plant of the more dominant millet were presumably normal responses to a situation in which this crop was essentially growing at a low population of its own species.

Leaf area index

The LAI of sole groundnut increased relatively little during the first three samples but thereafter it increased very rapidly and reached a peak value of just over 3 at 61 days (Fig. 3a). The LAI of sole millet increased very rapidly up to a peak of 2.4 at 47 days (i.e. just after 50% flowering) and thereafter it declined quite sharply (Fig. 3b).

Intercrop effects showed a similar pattern to that observed with total dry matter, i.e. the groundnut component achieved LAIs somewhat similar to

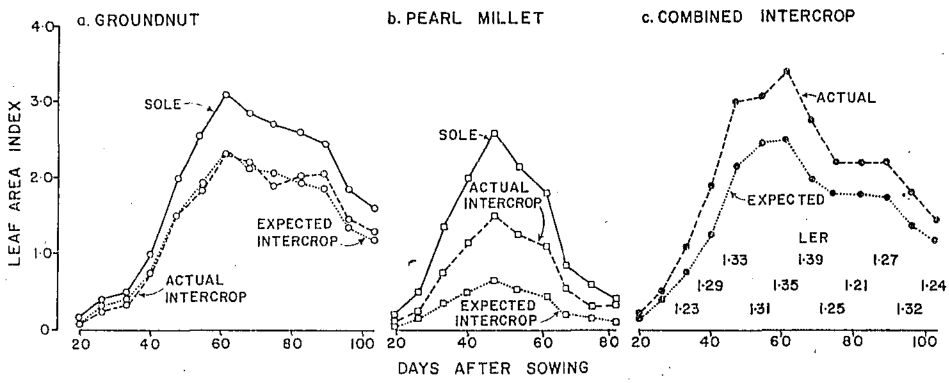

Fig. 3. Sole crop leaf area indices, and actual and expected intercrop leaf area indices for groundnut and millet (see text for explanation of expected values).

expected while the millet produced much higher LAIs than expected. However, for the combined intercrop the leaf area effects were rather greater than the total dry matter effects; throughout the peak period of growth there was an increase in total leaf area of more than 30%, with the biggest increase of 39% (LER = 1.39) occurring at 75 days (Fig. 3c).

Root densities

Detailed rooting patterns at the different profile depths will be presented elsewhere, so Table III shows only the mean densities for each cropping treatment at each sampling time. The fine roots of the two crops could not be easily distinguished so the intercrop is shown as the total of both crops averaged over the full 1:3 row pattern. Of the two sole crops, millet had a consistently higher root density. The LER values for total root length in the intercrop were mostly greater than 1, indicating greater root length in intercropping compared with sole cropping, but these LER values were lower than those for total dry matter or leaf area, suggesting that below-ground effects may have been less than above-ground effects. However, the LER calculations of root length had to assume that the ratio of root length/above-ground dry matter for each intercrop was the same as measured in sole cropping and this may not have been so.

Light interception and the efficiency of light energy conversion

Light interception in the sole millet increased very rapidly reaching a maximum of 85% at about the time of peak LAI (47 days) but then declining quite sharply (Fig. 4). Interception increased more slowly in the sole groundnut; by about 65 days it was a little below 80% and thereafter it gradually increased to a maximum of 85% at about 90 days.

During the earlier period of growth, light interception in the intercrop lay

TABLE III

Mean root densities (cm/cm^3 soil) at different stages throughout the season

Days after sowing	25	32	40	47	56	68	79
Sole groundnut	0.06	0.08	0.17	0.21	0.26	0.27	0.24
Sole millet	0.07	0.14	0.29	0.35	0.37	0.31	0.31
Combined intercrop	0.07	0.10	0.19	0.28	0.34	0.32	0.28
LER for total root length	1.08	1.04	1.00	1.18	1.18	1.15	1.10

between the two sole crop values, but by about 70 days it reached a maximum interception of just over 80%, at which stage interception by all three treatments was very similar. Interception then declined in the intercrop, presumably because of leaf senescence in the millet component. After millet harvest, interception by the remaining groundnut was fairly stable at just over 60% until it declined a little just before final harvest.

The efficiency of light energy conversion, in terms of dry matter produced/unit of light energy intercepted, is given for the weekly sampling periods in Table IV. An expected efficiency for the combined intercrop was calculated as the efficiency that would have been achieved had each component crop converted light energy at the same efficiency as its sole crop. For each sampling interval the actual intercrop efficiency was greater than the expected value and measured over the whole sampling period (26—103 days) the increase was 30%. This figure agrees very closely with the intercropping dry matter yield advantage of 28%, suggesting that this improved efficiency of light energy conversion was a major factor in producing a higher yield in intercropping. It is of particular interest that despite the appreciably higher LAI supported by the intercrop there was virtually no increase in the actual amount of light energy intercepted. It seems likely, therefore, that the "two-tiered" canopy of the intercrop gave a greater efficiency of conversion because light was more efficiently spread over a larger surface of leaf.

Soil water use

The total water use (i.e. transpiration plus evaporation from the soil surface) by sole millet and sole groundnut over their full growing periods was 30.3 and 36.8 cm, respectively. The total water use of 40.6 cm by the intercrop was greater than either sole crop but it was 11% less than the total water use 'expected' if each component had used water at its sole crop efficiency. Thus the 28% higher dry matter yield of the intercrop could only be partly explained on the basis of greater total water use and it must have been partly due to an increase in total water use efficiency (i.e. dry matter production/unit of total water used). However, if water use was based only on transpiration (calculated by the ICRISAT Environmental Physics staff

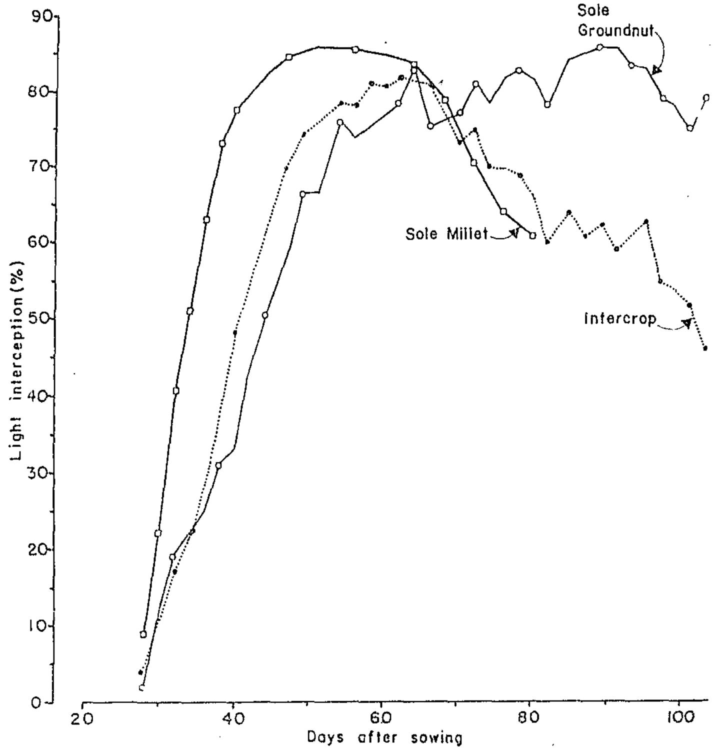

Fig. 4. Light interception by sole crops and an intercrop of pearl millet and groundnut.

TABLE IV

Weekly mean values of efficiency of dry matter production/unit of light intercepted for sole crops and the combined intercrop (g/mJ)

Days after sowing	Sole groundnut	Sole millet	Expected intercrop efficiency	Actual intercrop efficiency
26—33	0.48	1.20	0.70	1.82
33—40	1.44	1.90	1.66	1.95
40—47	1.49	2.90	2.32	2.68
47—54	1.33	1.71	1.55	2.37
54—61	1.09	1.55	1.30	1.65
61—68	0.60	0.95	0.75	1.22
68—75	0.28	0.81	0.50	0.51
75—82	0.11	0.04	0.05	0.44
82—89	0.20	—	0.20	0.38
89—96	0.49	—	0.49	0.57
96—103	0.44	—	0.44	0.76
26—103	0.60	1.32	0.83	1.08

from the proportions of intercepted and transmitted light energy) the actual and expected water use values were very similar at 22.79 and 23.74 cm, respectively. The increased total water use efficiency of the intercrop was achieved, therefore, not because of any increase in the dry matter production/unit of transpired water, but simply because a greater proportion of the total evapotranspiration was used by the crop rather than lost as evaporation from the soil surface.

Nutrient uptake

The percent N, P and K content of each crop as a sole crop or intercrop is given in Fig. 5. A consistent, though non-significant, effect for all three nutrients in the early growth stages was a slightly higher nutrient content in the intercrop millet compared with sole millet. A similar but more pronounced effect has been observed in sorghum when intercropped with pigeonpea and this was attributed to a greater competitive ability of the cereal (Natarajan and Willey, 1980). There was no evidence that intercropping had any consistent effect on the nutrient content of the groundnut.

Because of little change in the nutrient contents, total nutrient uptake largely reflected the dry matter effects observed earlier. The LER values for uptake of N, P and K at final harvests were 1.25, 1.28 and 1.26, respectively. These values were very similar to the LER of 1.28 for total dry matter, indicating that the greater yield from intercropping was associated with a greater, and commensurate, uptake of nutrients. For P and K this represents a greater depletion of soil nutrients. For N, soil depletion would also depend

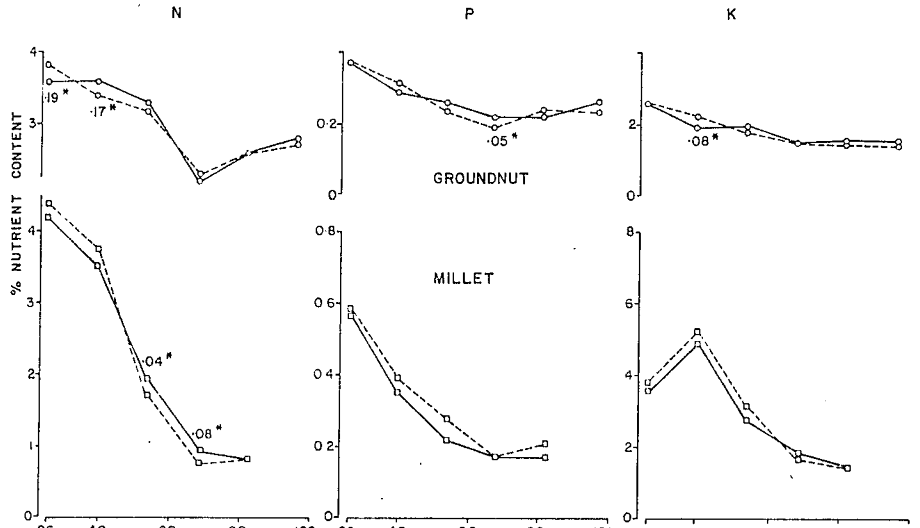

Fig. 5. Concentration of N, P and K in pearl millet and groundnut in sole cropping (——) and intercrop (- - - - - -); *LSDs at 5% given only where differences are significant.

on N fixation and it is of interest that Dart (1981) showed that in this same experiment the intercrop groundnut had less nodules and much lower fixation/plant than in sole cropping. Although this may be an explicable response in terms of shading, it is rather surprising in view of the fact that overall groundnut growth was little effected by intercropping, and it must mean that in intercropping the groundnut made greater demands on soil N. A further feature of the N situation is that an intercrop millet plant received the same amount of N fertilizer as a sole millet plant but it produced approximately twice the dry matter yield. This can be interpreted as a greater efficiency of use of applied nitrogen by the intercrop millet but, like the reduced fixation, it would result in greater soil depletion.

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