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Contribution of Nitrogen to Growth of Maize in Legume-maize Rotation on Limed Ultisols

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ABSTRAK

Pengunaan kapur dan sisa tanaman kekacang merupakan pendekatan yang sesuai untuk mengatasi masalah kandungan aluminium yang tinggi dan kandungan N setempat yang rendah menghadkan produktiviti tanaman makanan jangkapendek pada tanah Ultisol. Dengan menggunakan kaedah ini, nilai sumbangan nitrogen kepada tanaman jagong di dalam tiga sistem giliran kacang tanah (L)-jagong (M) (LMLM) telah ditaksirkan. Taksiran dilakukan dengan menolak jumlah pengambilan N oleh jagong pada petak tanpa baja N dalam sistem tanaman tunggal daripada jumlah pengambilan N oleh jagong pada petak sistem tanaman giliran kacang tanah-jagong yang tertentu. Keputusan menunjukkan tanah Ultisol yang dikapur berkeupayaan menampung peningkatan hasil tanaman kacang tanah dan jagong. Dalam sistem tanaman giliran kacang tanah-jagong, purata anggaran N yang disumbangkan kepada jagong selepas satu, dua dan tiga kali tanaman kacang tanah berturutan adalah sebanyak 19, 33, dan 56 kg N ha^{-1}. Anggaran 56 kg N ha^{-1} merupakan satu per tiga daripada syor baru keperluan N (159 kg ha^{-1}) untuk tanaman jagong.

ABSTRACT

Liming of soils and the use of legume residues in a crop rotation are considered good approaches to reduce the constraints of high aluminium and low native nitrogen affecting annual food crop production in Ultisols. Using this approach the values of nitrogen contributed to maize in three groundnut (L)-maize (M) sequences (LMLM, MLLM and LLLM) in an intensive rotational cropping system were estimated. The estimates were made by subtracting the total N-uptake by maize in the zero N-fertilized monocropping from the total N-uptake by maize under the respective legume-maize rotation. The results showed that it is possible to sustain an increased yield of groundnut and maize on limed Ultisols. In the groundnut-maize cropping system, the average N contribution was after one, two and three successive groundnut crops was 19, 33, and 56 kg N ha^{-1}. The latter estimate is about one-third of the newly recommended total N requirement of maize, 159 kg N ha^{-1}.

INTRODUCTION

In Malaysia about 120,000 ha of highly weathered Oxisols and Ultisols under rubber or oil palm are replanted annually. Annual crops such as groundnut and maize are often used as cover crops, which can replace non-food legume cover crops, during the first four years under the replanting programme. The acidic nature associated with high aluminium concentration and low native nitrogen status often are severe constraints to the growth and productivity of annual food crops on these Ultisols.

The value of atmospheric nitrogen (N_2) fixed by groundnut ranges from 72 to 297 kg ha^{-1} (Nutman 1966: Gibson *et al.* 1982; FAO 1984) while the value of N contributed to the soil has been estimated to be between 26 and 60 kg ha^{-1} (Jones 1974; Giri and De 1980). These values were derived from estimations based on N_2 fixed over one season of groundnut which almost entirely depended on the native rhizobia. Seed inoculation with specific *Bradyrhizobium* strains has been shown to increase growth and yield of groundnut (Faizah *et al.* 1985). Consequently, the practice is useful in a crop rotation system involving groundnut and maize.

In Malaysia the high acidity and Al saturation of Ultisols have been shown to reduce growth and yield of groundnut (Foster *et al.* 1980). Earlier research has not, however, provided sufficient information on the N economy of a groundnut-based crop production system for soils with low pH and high Al saturation.

A field study was undertaken, using maize yield data, to estimate the amount of N contributed by inoculated groundnut grown on limed Ultisols.

MATERIALS AND METHODS

Two long-term field experiments were conducted from 1981 to 1984. Two cropping systems were carried out simultaneously: (1) groundnut-maize rotational cropping system and (2) inorganic N-fertilized maize monocropping system.

1. *Groundnut-maize rotational cropping system*

The experimental site, a former secondary forest, was ploughed twice and rotovated three times before lime was applied at an equivalent rate of 4 mt GML ha^{-1} to raise the soil pH (1:2.5 with H_2O) from 4.2 to 5.5. The Bungor soil (Typic Paleudult) was limed after each cropping to maintain the same initial pH for all subsequent croppings throughout the experiment. This was followed by basal dressing with 56 kg P_2O_5 as TSP and 56 kg K_2O as MOP. No nitrogenous fertilizer was applied.

A pre-emergent herbicide, Lasso, was sprayed immediately after sowing while the insecticide Malathion was regularly applied after crop emergence. Weeding was done manually when necessary.

Groundnut seeds cv. V13, which were previously treated with the fungicide Thiram, were inoculated with *Bradyrhizobium* strain CB756 and sown in prepared plots, each measuring 5 m by 8 m. Two seeds were planted in each planting hole at 25 cm x 30 cm spacing and thinned a week later to a final plant population of *ca.* 133,000 ha^{-1}. The experimental plots were arranged in randomized complete block design with 6 replications.

The legume crop was harvested 106 d after planting (D_{106}). Pods were removed and the total weight of residue taken after each harvest. N concentrations were determined at each harvest. Similar measurements were done to all other subsequent groundnut crops during the study period. The residues were returned to the soil as green manure to provide nitrogen for the subsequent crop. Prior to each planting, ten random soil cores (0-20 cm) were collected from each plot. They were bulked, dried, ground, sieved (2 mm) and stored in polythene bags at 4°C. The available soil N ($NH_4^+ + NO_3^-$) from these core samples was determined before cropping using the method outlined by Bremner (1965).

After a fallow period of about three to four weeks, the same plot was prepared for another crop of either maize or groundnut, according to the cropping sequence (Table 1). In either case, the subsequent crop would receive similar basal fertilizers and, where applicable, N from groundnut residues returned to the respective plot at harvest (D_{106}). The maize residue, however, was not returned to the soil but its total N uptake along with that of the grain was determined at each harvest using the methods outlined by Chapman and Pratt (1961). Final harvest of maize took place 78 d (D_{78}) after planting.

TABLE 1
Groundnut-maize sequence used in the rotational cropping system on limed Ultisols (1981-1984)

fertilizer rate ($kg\ ha^{-1}$)			groundnut-maize cropping sequence	
N	P_2O_5	K_2O	1st cycle (1981-1982)	2nd cycle (1983-1984)
0	56	56	L M L M	L M L M
0	56	56	M L L M	M L L M
0	56	56	L L L M	L L L M

L: legume M: maize

2. *Nitrogen-fertilized Maize Cropping System*

An inorganic nitrogen-fertilized maize monocrop was established simultaneously with the groundnut-maize rotational cropping system on an area separated by 3 m wide grass border from the latter. All field operations including liming to pH 5.5 were similar to those in the rotational cropping system. Five levels of N: 0, 45, 90, 135 and 180 kg N ha^{-1} (N_0, N_1, N_2, N_3 and N_4) were applied to the respective maize plots; half of these rates were applied together with the basal P and K fertilizers two weeks before sowing. The remainder of the fertilizer N was applied approxi-

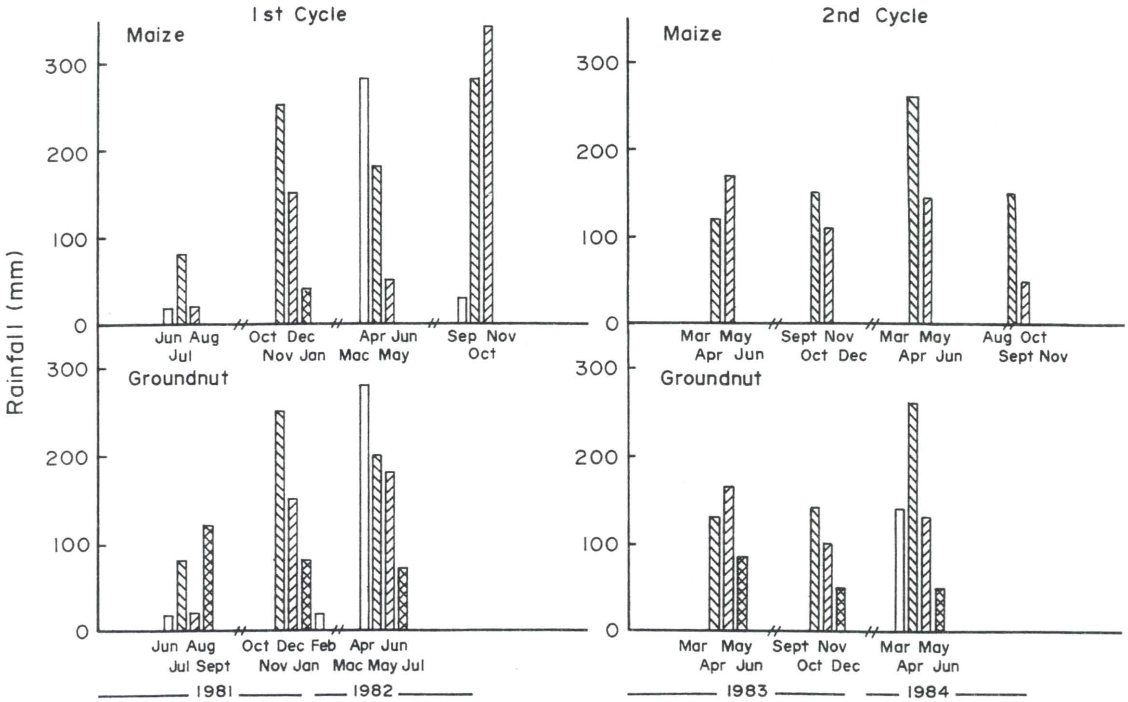

Fig. 1: Cropping season and rainfall pattern during the field trial

mately 10 d before tasselling. Thiram-treated maize seeds (var. Sg. Buluh 3) were planted at a spacing of 25 cm x 75 cm to give a plant population of *ca.* 53000 ha^{-1}. Experimental plots were arranged in a randomized complete block design with 4 replications with regular applications of insecticide and manual weeding. Maize cobs were harvested at D_{78} after which 10 random maize stubbles from each plot were chopped, dried at 60°C for seven days, weighed, and analysed for N. The grain and stover samples were ground

TABLE 2

Selected chemical characteristics of Bungor sandy clay loam (Typic Paleudult) at the experimental site

C ($g\ kg^{-1}$)	16.83
pH (1:2.5 in H_2O)	4.23
pH (1:2.5 in 1M KCL)	3.34
N ($g\ kg^{-1}$)	1.10
P ($mg\ kg^{-1}$)	10.81
K [cmol(+)kg^{-1}]	0.19
Ca [cmol(+)kg^{-1}]	0.34
Mg [cmol(+)kg^{-1}]	0.24
Al [cmol(+)kg^{-1}]	3.48
ECEC [cmol(+)kg^{-1}]	4.25
*Al saturation (%)	82.00

* Based on effective cation exchange capacity (ECEC)

and their N concentrations determined by micro-Kjeldahl method (Bremner 1965).

Two cropping seasons were carried out each year. All crops, except those in the first season of 1981, were planted at the onset of the rainy season to avoid the drought period. The rainfall pattern recorded at the experimental site is presented in *Fig. 1.*

Plant and Soil Analyses

All plant tissues were prepared for analysis by the dry-ashing method outlined by Chapman and Pratt (1961). Concentrations of N were determined with the Technicon Auto Analyzer.

Composite soil cores (0-20 cm) from all cropped plots were collected randomly. These soil cores were bulked, air-dried, ground, sieved (2 mm) and analysed for N. The selected chemical characteristics of the soil before the experiment are given in Table 2.

Estimates of N Contributed by Groundnut

The N contributed by 1, 2 or 3 successive groundnut crops to maize was estimated by subtracting the total N-uptake of maize in the zero N-fertilized (N_0) monocropping experiment from the total N-uptake by maize succeeding

TABLE 3
Dry matter yield of groundnut in the rotational cropping system (1981-1984)

Crop Sequence		1st crop cycle (1981-1982) DM Yield (mt ha^{-1})			2nd crop cycle (1983-1984) DM Yield (mt ha^{-1})	
	Haulm	Pod	Total	Haulm	Pod	Total
(a)						
L	1.46	1.24	2.70	2.35	2.00	4.35
M	-	-	-	-	-	-
L	2.26	2.16	4.42	2.68	2.16	4.84
M	-	-	-	-	-	-
(b)						
M	-	-	-	-	-	-
L	2.61	1.91	4.52	2.28	2.16	4.44
L	2.37	1.90	4.27	2.63	2.22	4.85
M	-	-	-	-	-	-
(c)						
L	1.80	1.20	3.00	2.29	1.90	4.19
L	2.39	2.02	4.41	2.79	2.09	4.88
L	2.85	2.07	4.92	2.94	2.25	5.19
M	-	-	-	-	-	-

groundnut under the respective legume-maize rotation. An estimate was also made by comparing the performance of this maize crop with the response curve developed using the total N-uptake data obtained from the N-fertilized monocropping experiment (MacColl 1989b).

Statistical Analyses

Statistical analyses on all data collected and polynomial curve fitting were conducted using the Statistical Analysis System (SAS) Package. An analysis of variance and significant differences was determined using the general linear model (GLM) (SAS, 1979) and contrast method respectively (Snedecor and Cochran 1973; Steel and Torrie 1980).

RESULTS AND DISCUSSION

(a) Crop Yield under Rotational and Mono-cropped Systems

Dry Matter Yield of Groundnut

In the cropping sequence where groundnut was grown alternately with maize (LMLM) for four years (1981-1984), total dry matter (DM) yield of groundnut (inoculated with *Bradyrhizobium* CB756) growing on limed Ultisols ranged from 2.70 to 4.84 mt ha^{-1} per season (Table 3a). From this total DM yield the haulm ranged from 1.46 to 2.68, and pods from 1.24 to 2.16 mt ha^{-1}. In the cropping sequence where maize was the first crop on the limed Ultisols, followed by two groundnut crops before being put to another maize crop (MLLM), the total DM (Table 3b) fell within the same upper range as in the earlier sequence (LMLM).

In the sequence where three successive groundnut crops were grown, followed by a maize crop (LLLM), the total DM ranged from 3.00 to 5.19; haulm 1.80 to 2.94 and pod yield 1.20 to 2.25 mt ha^{-1} (Table 3c). The pod yield obtained in this study was comparable with that obtained elsewhere in Malaysia (Halim and Ramli 1980; Foster *et al.* 1980). Except for the last sequence (LLLM), there was no clear legume crop phase as originally done by Yaacob and Blair (1979). Nevertheless, the total DM reflects the actual conditions as they exist under field situations in Malaysia. It was most likely that the maintenance of appropriate edaphic conditions through liming had produced the rather consistent DM yield of groundnut. Apart from the first legume crop in the sequence LMLM and LLLM, about 2.1 mt ha^{-1} of pod and 2.5 mt ha^{-1} haulm were obtained. The latter was returned to the soil after each crop as a source of N in the crop rotation.

TABLE 4
Plant N content of groundnut in the rotational cropping system (1981-1984)

Crop sequence	1st crop cycle (1981-1982) N content (kg ha^{-1})			2nd crop cycle (1983-1984) N content (kg ha^{-1})		
	*Haulm	Pod	Total	Haulm	Pod	Total
(a)						
L	26.49	43.95	70.44	50.37	71.62	121.99
M	-	-	-	-	-	-
L	48.71	73.84	122.55	53.08	77.25	130.33
M	-	-	-	-	-	-
(b)						
M	-	-	-	-	-	-
L	54.75	68.58	123.33	49.29	80.50	129.79
L	50.90	68.94	119.84	53.08	79.18	132.80
M	-	-	-	-	-	-
(c)						
L	30.35	43.83	74.18	49.07	69.81	118.88
L	51.47	74.47	125.65	57.50	75.45	132.95
L	59.86	74.23	134.09	58.75	80.41	139.16
M	-	-	-	-	-	-

* returned to the soil

Plant Nitrogen

In the LMLM sequence, the first legume crop did not produce much plant N (Table 4a). The relatively low production could be due to the low rainfall during the growing season (*Fig. 1*). Apart from this first legume crop, legume N was maintained between 122.0 to 130.3 kg ha^{-1} throughout the four-year study period (Table 4). Similarly, except for the first crop, more than 45 kg N ha^{-1} was returned to the soil through the legume residues. Another 74 kg N ha^{-1} in nuts representing 59% of total legume N was removed in the form of pods.

When the same soil from different plots was first cropped to maize in the MLLM sequence, the following two successive legume crops produced a consistent amount of legume N returned to the soil during the same four-year period (Table 4b). Around 53 kg N ha^{-1} was returned to the soil; nearly 69 kg N ha^{-1} was removed in the pod for the first two-year crop cycle and around 80 kg N ha^{-1} in the second crop cycle two years later (Table 4b). In terms of total legume N produced, the amount ranged from 120 to 133 kg ha^{-1}, which was about the same as in the previous crop sequence (LMLM).

In the sequence where the soil remained longer under the legume phase (LLLM), the total legume N yield varied from 74 to 139 kg N ha^{-1} (Table 4c). Except for the first legume crop in the first crop cycle, which was low yielding and comparable to the first crop of the LMLM sequence due to lack of rainfall (*Fig. 1*), there was a steady increase in legume N as the legume cropping intensity increased especially in the second two-year crop cycle (1983-1984). This suggested that some of the N returned to the soil in residues had been utilized by the following legume crop, and part of this may have also been removed in the nuts. If so, this followed the usual pattern whereby grain legumes removed a large proportion of their fixed N in nuts. In these three successive crops, the pods, which contained about 55 - 62% of total plant N, were removed from the soil-plant system and, therefore contributed nothing to the succeeding maize crop. The remaining 38 to 45% of plant N contained in the residues was returned to the soil at the end of each groundnut season.

Soil Nitrogen

There was a relatively high available N level of 89 to 95 kg ha^{-1} in all plots prior to the first planting (Table 5). In the LMLM plots, available N remained at a high level (87 kg N ha^{-1}) before the planting of maize due to the addition of 26

TABLE 5
Available N in soil before sowing in each season in the rotational cropping system (1981 - 1984)

Crop sequence	1st crop cycle (1981-1982)	2nd crop cycle (1983-1984)
	Available N (kg ha^{-1})	Available N (kg ha^{-1})
(a)		
L	95.40	57.32
M	86.72	72.89
L	65.86	65.71
M	72.09	76.42
(b)		
M	88.56	58.69
L	62.58	56.72
L	68.57	61.48
M	73.73	76.89
(c)		
L	94.82	51.66
L	79.88	75.34
L	82.47	80.83
M	86.48	90.41

kg N ha^{-1} from the first legume crop (Table 5a). After the first maize crop, the level of available N before the planting of groundnut in the third season was 66 kg N ha^{-1}, a lower amount since no residual N was added. A similar trend was observed for the remaining seasons throughout the four-year period. The same trend was also observed in the MLLM sequence after the first maize crop where lower amounts of available N were detected before the planting of groundnut. The available N in the same plot had increased to 74 and 77 kg N ha^{-1} after two successive legume crops in the first (1981-1982) and second (1983-1984) crop cycles, respectively (Table 5b). This was possible because the accumulated legume N from successive legume crops when subjected to periodic wetting and drying cycles under field conditions would stimulate the decomposition of N-rich legume residues (Wetselaar 1967; Yaacob and Blair 1980). The total available N before the second maize planting was about the same for both crop sequences (LMLM and MLLM). Higher available N (86 and 90 kg N ha^{-1}) was found in plots after three successive groundnut crops (LLLM) and prior to planting with maize (Table 5c). In all the three crop sequences, the component of legume residual N in the available N before each maize crop was considered the main source of N. The available N represents the organic N of recently added as well as accumulated plant N that was mineralized under field conditions imposed in this experiment. It was observed that every time after the incorporation of the legume residue into the soil, there was an increase in available N before each subsequent crop was planted. However, after each maize crop the available N prior to the next crop planting was low as expected due mainly to no addition of a crop residue and removal by the maize. Under this N depleted condition, whenever groundnut was used in the preceding crop more N accumulated in the plant system, the extra N must have been obtained through N_2 fixation.

Total Dry Matter Yield of Maize

In the LMLM cropping sequence, the total DM yield of maize after a legume crop ranged from 6.1 to 7.2 mt ha^{-1} per season (Table 6a). In the MLLM sequence, the maize DM yield after two successive legume crops was relatively higher (7.1 and 7.9 mt ha^{-1}). The DM yield of maize after three successive legume crops (LLLM cropping sequence) was the highest , 8.5 and 9.9 mt ha^{-1} (Table 6c). The total DM yield increased with increase in legume cropping intensity indicating the influence of cumulative residual legume N. Since no fertilizer N was applied in the rotational

TABLE 6
Dry matter yield of maize under different groundnut-maize rotational cropping systems (1981-1984)

Crop sequence	1st crop cycle (1981-1982)			2nd crop cycle (1983-1984)		
	DM Yield (mt ha^{-1})			DM Yield (mt ha^{-1})		
	Stover	Grain	Total	Stover	Grain	Total
(a)						
L	-	-	-	-	-	-
M	2.56	3.91	6.47	2.52	3.58	6.10
L	-	-	-	-	-	-
M	3.13	3.86	6.99	2.94	4.22	7.16
(b)						
M	2.82	3.32	6.14	2.26	2.77	5.03
L	-	-	-	-	-	-
L	-	-	-	-	-	-
M	3.14	3.99	7.13	3.63	4.29	7.92
(c)						
L	-	-	-	-	-	-
L	-	-	-	-	-	-
L	-	-	-	-	-	-
M	4.14	4.36	8.50	4.77	5.09	9.86

system, the yield data reflected the supply of N derived from native soil N and decomposition of the preceding legume crop. This in turn depended on the total dry matter yield or the vegetative vigour of the legume crops, its seed yield in relation to its vegetative growth, and the possible loss of available N before it could be absorbed by the following maize crop. While it was possible for groundnut to leave a zero residual N (MacColl 1989a), the opposite was true in this study, despite a considerable leaching expected during the four-year cropping period.

In the monocropped maize experiment, maize showed a positive response to N application except for the first season which was erratic due to poor rainfall (*Fig. 1*). This indicated that after the first season of maize, the N present in the soil was insufficient for satisfactory yield. Increments in fertilizer-N up to 135 kg ha^{-1} produced a corresponding increase in yield (*Figs.* 2a and 2b). Beyond this rate, the maize plant experienced a luxury consumption which led to excessive growth of vegetative parts and possibly delayed plant maturity. This subsequently lowered the yield, since harvest was fixed at 78 d for all maize crops (Gauch 1972), and increased the

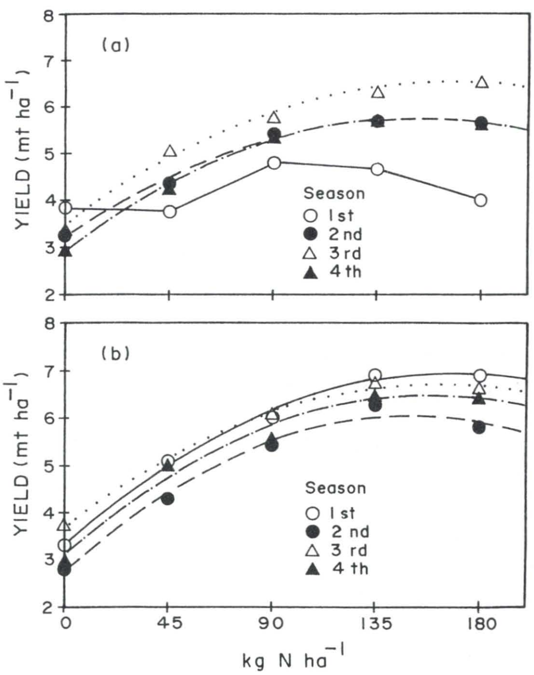

Fig. 2: Influence of fertilizer-N on the grain yield of maize during (a) 1st (1981-1982) and (b) 2nd (1983-1984) crop cycles

TABLE 7
Regression analysis of grain yield of maize during (a) 1st (1981-82) and (b) 2nd (1983-1984) crop cycles in monoculture cropping system

(a) 1st Crop Cycle

Season	Regression	Predicted maximum yield	Quantity of N required to produce maximum yield
		mt ha^{-1}	kg ha^{-1}
2	3.22+0.033X-0.11x10-3 X^2	5.69	153.15
3	3.48+0.037X-0.11x10-3 X^2	6.59	166.19
4	2.92+0.038X-0.12x10-3 X^2	5.92	151.70

(b) 2nd Crop Cycle

Season	Regression	Predicted maximum yield	Quantity of N required to produce maximum yield
		mt ha^{-1}	kg ha^{-1}
1	3.33+0.042X-0.12x10-3 X^2	7.00	172.91
2	2.72+0.044X-0.15x10-3 X^2	5.95	149.72
3	3.69+0.037X-0.11x10-3 X^2	6.80	163.45
4	3.12+0.042X-0.13x10-3 X^2	6.51	158.69

N content of the stover. The highest grain yield was 6.92 mt ha^{-1}, obtained from the first cropping in the second crop cycle where 135 kg N ha^{-1} was applied (*Fig.* 2). Between seasons, there was variation in the trend of yield response. Except for the first crop in 1981, those planted during first and third seasons of each cycle produced higher yields. This differential response could be due to the result of agroclimatic variations.

A polynomial response equation was fitted for the grain yield of the two cycles and a quadratic response resulted with the increasing rate of fertilizer N applied (*Fig. 2*). The quadratic response of grain yield to fertilizer N indicated that luxury levels of nitrogen had been reached. The predicted maximum yield for the first cycle ranged from 5.69 to 6.59 mt ha^{-1} with the corresponding fertilizer N rate of 152 to 166 kg N ha^{-1}. For the second crop cycle it ranged 5.95 to 7.00 mt ha^{-1} when fertilized at 150 to 173 kg N ha^{-1} (Table 7). These fertilizer N rates are higher than those recommended by the Department of Agriculture of Malaysia for maize on sedentary soils (Jabatan Pertanian Malaysia 1982). The data suggest a re-examination of what constitutes a recommended fertilizer N rate for maize on Bungor sandy clay loam. Average grain yields for the plot receiving no fertilizer N were 3.37 mt ha^{-1} (58.9% relative to maximum yield) and 3.22 mt ha^{-1} (48.8% relative to maximum yield) for the first and second cycles, respectively.

(b) N Contribution by Groundnut

The total DM yield (grain and stover) and total N uptake by maize cropped on soil to which varying amounts of legume residues were added were used to estimate the amount of N contributed by the legume crop. This estimate was further compared to values for using the same parameters in maize from the inorganic N-fertilized monocropping experiment.

A closer examination of the total dry matter (DM) and N uptake (NU) data from maize grown on soils under different crop sequence compared to those from the zero N-fertilized monocropped experiment showed significant positive trends in

TABLE 8

Total DM (mt ha^{-1}) and N uptake (kg N ha^{-1}) of maize on limed Ultisols receiving varying number of groundnut crops or rates of fertilizer-N at Puchong, Malaysia

No. of previous legume crops	rotation		monoculture [Fertilizer N (kg $^{ha-1}$)]									
	(Legume N)		0 (Control)		45		90		135		180	
	DM	NU	DM	NU	DM	NU	DM	NU	DM	NU	DM	NU
1st crop cycle												
	6.47	68.05	6.17	56.25	8.47	88.94	10.24	111.90	11.65	118.25	10.98	119.31
LMLM	6.99	65.28										
LLLM	8.50	87.67	5.76	50.78	8.57	77.15	10.17	105.93	11.98	123.26	11.16	118.75
MLLM	7.13	73.80										
	6.14	71.74	7.54	71.79	7.48	70.71	9.31	97.74	8.80	88.90	7.82	76.02
2nd crop cycle												
	6.10	63.04	5.10	45.43	8.60	79.37	10.02	104.39	11.87	124.07	10.89	114.38
LMLM	7.16	74.24										
LLLM	9.86	97.40	6.02	50.35	9.32	89.27	10.80	110.40	12.65	134.05	12.20	131.14
MLLM	7.92	79.55										
	5.03	61.18	6.50	57.92	9.74	99.58	11.00	123.70	13.02	153.42	13.20	155.69

DM: total DM yield NU: total N uptake

the N-balance due to the groundnut-maize rotational system on limed Ultisols (Table 8).

Where maize was grown after one legume crop (LMLM) for four years (1981-1984), the total DM yield values (6.47 and 6.99 mt ha^{-1}) were equivalent to those between control and 45 kg N ha^{-1} plots (6.17 and 8.47 mt ha^{-1}, respectively) in the monocropping experiment. Similar results were obtained with the maize yield after two successive groundnut crops (7.13 mt ha^{-1}) as observed in the MLLM crop sequence. A similar trend was observed in the N-uptake values. However, when three groundnut crops were grown and later followed by a maize crop (LLLM) a higher total DM yield (8.50 mt ha^{-1}) and N uptake value (87.67 kg N ha^{-1}) were obtained (Table 8). From these data, it is possible to estimate the percentage of legume-N contributed by groundnut under the various rotational cropping sequence. For example, in the LMLM cropping sequence:

% increase in total yield =

$$\frac{\text{Total yield after one legume crop } (6.47 \text{ mt ha}^{-1}) - \text{Total yield in zero N-fertilized plot } (6.17 \text{ mt ha}^{-1})}{\text{Total yield in zero N-fertilized plot } (6.17 \text{ mt ha}^{-1})} \times 100$$

In the 1981 cropping season, the legume N contributed by one groundnut crop produced about 5 % increase in total DM yield of maize (Table 9a). This was expected as the growing season experienced a poor rainfall (*Fig. 1*). Since then (1982-84), groundnut alternated with maize (LMLM) contributed an average increase close to 20 % total maize DM yield (Table 9a), which is comparable to that estimated by MacColl (1989b). In the cropping sequence where two groundnut crops were grown prior to a maize crop (MLLM), the latter produced a 24 % increase in yield during the first crop cycle and around 32 % during

TABLE 9
Percentage increase in, and fertilizer equivalent of DM yield of maize in the rotational cropping system

Crop sequence	1st crop cycle (1981-1982)		2nd crop cycle (1983-1984)	
	% Increase in Total DM	Fertilizer N equivalent (kg ha^{-1})	% Increase in Total DM	Fertilizer N equivalent (kg ha^{-1})
a)				
L	-	-	-	-
M	4.86	5.87	19.60	19.70
L	-	-	-	-
M	19.61	12.86	18.94	15.55
b)				
M	-	-	-	-
L	-	-	-	-
L	-	-	-	-
M	23.78	21.94	31.56	25.91
c)				
L	-	-	-	-
L	-	-	-	-
L	-	-	-	-
M	47.57	43.88	63.79	61.42

the second crop cycle (Table 9b). In a crop sequence where three successive legume crops were grown (LLLM), the legume N contributed towards an increase of 48% and 64% in maize DM yield during the first and second crop cycle, respectively (Table 9c).

These percentages can be equated to the fertilizer equivalent without referring to the response curves developed from the inorganic N-fertilizer monocropped experiment but by a direct comparison using the response of DM up to 90 kg N ha^{-1} which showed a highly correlated relationship. All the maize yield responses in the rotational crop were observed to fall within this range. Beyond this fertilizer rate the specific yield response increased at a reduced rate. For the LMLM sequence, the fertilizer-N (DM) equivalent derived after the first and second legume crop were 6 and 20 kg ha^{-1}, respectively, for the first crop cycle, and 13 and 16 kg ha^{-1}, respectively, for the second crop cycle (Table 9a). For the MLLM, the fertilizer-N (DM) equivalent derived after two successive legume crops in the first and second crop cycles were 22 and 26 kg ha^{-1}, respectively (Table 9b). With three succes-

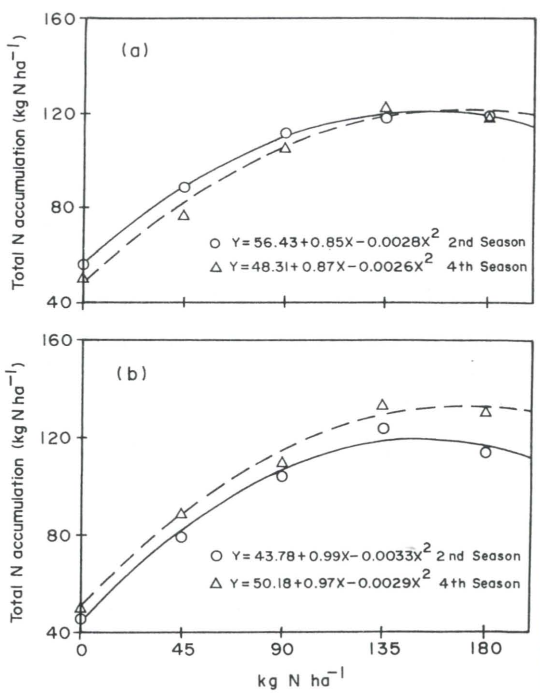

Fig. 3 : Effect of fertilizer-N on the total-N accumulation during (a) 1st (1981-1982) and (b) 2nd crop cycles

sive legume crops (LLLM) the amount of fertilizer-N (DM) equivalent was 44 kg ha^{-1} for the first crop cycle and 61 kg ha^{-1} for the second crop cycle (Table 9c).

In addition to the N estimates obtained by direct comparison, the estimates contributed by the legume can also be equated to the fertilizer-N equivalent, obtained by comparing them with the response curves developed from the N-fertilized monocrop experiment. Using the higher coefficient of determination of the response curves for N uptake until 180 kg N ha^{-1} (*Fig.* 3a and 3b), it was possible to estimate the amount of N contributed by groundnut, a technique similar to that used by MacColl (1989b). The fertilizer-N estimates obtained after the first and second legume crop (LMLM) during the first crop cycle was 14.30 and 20.81 kg N ha^{-1}, respectively (*Fig.* 3a). During the second cycle in the next two years (1983-1984), the same crop sequence (LMLM) produced the respective fertilizer-N estimates: 13.39 and 26.82 kg N ha^{-1} (*Fig. 3b*). In the MLLM sequence the amounts of fertilizer-N estimates derived after two successive legume crops were 32.45 and 33.46 kg N ha^{-1} for the first and second crop cycle, respectively. The fertilizer-N equivalent produced after three successive legume crops (LLLM) was 53.9 for the first cycle and 58.6 kg ha^{-1} for the second crop cycle.

In practical terms, it is the fertilizer estimate contributed by the groundnut (or other annual grain legumes) that becomes important in a crop rotational practice. This N contributions was determined by averaging the estimates from the first (1981-1982) and second (1983-1984) crop cycles in all three groundnut-based sequences. The average N contribution in the LMLM, MLLM and LLLM sequence were 19, 33 and 56 kg N ha^{-1}, respectively. The amount of N contributed increased with increase in the number of successive groundnut crops which produced a cumulative effect of legume residual N. When more than one legume crop was grown it is expected that the N would be derived partly from the previous and newly added legume residue (Yaacob and Blair 1979). From *Figs 2a and 2b,* the average fertilizer-N required to produce maximum grain yield was 159 kg N ha^{-1}. The result implied that a substantial amount of N (56 kg N ha^{-1}) could be contributed by a legume residue especially after three successive groundnut crops. The N contributed which amounted to 35 % of the N requirement of maize is substantial in the nitrogen economy of a groundnut-based cropping system.

CONCLUSION

The data from this long-term (1981-1984) field experiment show that it is possible to sustain an increased yield of groundnut and maize on limed Ultisols. In the groundnut-maize cropping system, the average N contribution after one, two and three successive groundnut crops were 19, 33, and 56 kg N ha^{-1}. The last figure is about one-third of the recommended total N requirement of maize of 159 kg N ha^{-1} for Bungor soil.

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