ROOT DISTRIBUTION OF LEGUMINOUS COVER CROPS IN THE HUMID TROPICS AND EFFECTS ON A SUBSEQUENT MAIZE CROP

Key words: Leguminous Cover Crops Shoot: root Ratio Root Distribution *Mucuna pruriens utilis* *Vigna unguiculata* *Pueraria phaseoloides* *Centrosema macrocarpum* *Desmodium ovalifolium* *Calopogonium mucunoides* *Crotalaria anagyroides* *Crotalaria juncea*

Kurniatun Hairiah (1) and Meine van Noordwijk (2)
1. Soil Science Department, Faculty of Agriculture, Brawijaya University, Malang, Indonesia
2. Institute for Soil Fertility, Haren (Gr.), the Netherlands

Abstract

Leguminous cover crops can be used in the humid tropics to increase the production of subsequent food crops, through effects on nitrogen availability in the soil, suppression of weeds and/or changes in soil physical conditions. Nodulation, total root and shoot mass and depth of root development are important characteristics of cover crops.

Root development of several cover crops is described here for two sites with acid soils, in S.E. Nigeria and S. Sumatera, Indonesia. Short-lived annual species have a higher shoot: root ratio than perennial species. *Mucuna pruriens utilis* had the most shallow root system, but good nudulation and, through its fast growth, it was best in suppressing weeds (in a 4-month period).

Mucuna and *Crotalaria juncea* gave the best effect on a subsequent maize crop in an experiment on a dark grey alluvial soil in Malang, E. Java, Indonesia. Apart from being a source of N, the cover crops also had a positive effect on subsequent maize growth by increasing water storage in the soil and by improving root development of maize.

Introduction

In the humid tropics leaching of N and other nutrients to the subsoil may occur throughout the growing season. Efficiency of N-use under such conditions is often very low, due to lack of synchronization of crop demand for N with the mineralisation rate. The ability to develop deep root systems is important in this situation for recovery later in the growing season, of nutrients leached early on (Van Noordwijk, 1989). There may be variation in the demand curve of the crop and in the mineralisation rate, due to differences in soil microclimate or other factors (figure 1). Complete synchronization of supply and demand is almost impossible. The larger the difference between supply and immediate demand, the lower the adsorption of the nutrient to the soil and the higher the rainfall during the growing season, the deeper the nutrient will leach into the soil. Rooting depth required to recover nutrients leached early in the growing season will vary accordingly. Deep-rooted cover crops in the crop r[redacted]tation may [redacted]ver leached nutrients.

Leguminous cover crops can provide N-rich organic matter to the soil and thus decrease the need for N-fertilizer (Greenland, 1985). Apart from the direct N-supply to the next crop, cover crop biomass may improve soil physical conditions (Bouldin, 1988). Aboveground biomass production of cover crops is important as a source of organic matter and for its effects on weed growth. The root system of the cover crop is important for recovering nutrients from deeper layers and possibly for improving soil conditions for and root development of subsequent food crops. To be usefull as an intercrop between food crops, the cover crop should have few roots in the topsoil.

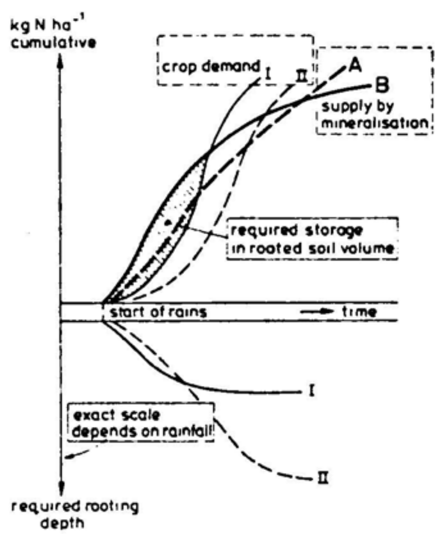

Figure 1. Schematic interactions between degree of synchronization of supply of nutrients by mineralisation and crop demand for N (upper part of the figure) and the rooting depth required for full recovery of leached N (lower part of the figure). Two situations of demand, a rapidly (I) and a slowly (II) establishing plant, and two situations of supply, a fast (B) and a slow (A) mineralisation rate, are shown.

The purpose of the research, presented here, was to select cover crops, to be used in crop rotations, with the following characteristics:

- rapid plant establishment and high biomass production, yielding a good soil cover and good weed control,
- deep root development,
- good nodulation and N-fixation.

Results will be discussed here for three locations: Onne (S.E. Nigeria), Ketapang (S. Sumatera, Indonesia) and Malang (E. Java, Indonesia). In Malang the effects of cover crops on a subsequent maize crop were tested as well.

TABLE 1. Soil properties of the fields used for cover crop experiments; O = Onne (S.E. Nigeria), K = Ketapang (S. Sumatera, Indonesia), M = Malang (E.Java, Indonesia)

Soil depth (cm)	pH (H_2O)	pH (KCl)	% N	% C	C/N	P-Bray II (ppm)	Exch. Cations (1 N NH_4OAc, me/100 g)				Total (me/100 g)
							K	Na	Ca	Mg	
O 0 - 5	4.5		0.111	1.78	16.0	78.7	0.17	0.21	1.03	0.46	1.64
5 - 15	4.5		0.071	1.31	18.5	54.0	-	0.19	0.64	0.21	1.80
15 - 25	4.5		0.061	0.98	16.1	47.7	-	0.16	0.74	0.05	2.01
25 - 40	4.5		0.082	0.73	8.9	46.8	-	0.24	0.56	-	2.05
K 0 - 3	6.10	5.20	0.14	1.73	12.3	5.0	0.75	0.66	2.80	2.25	
3 - 29	4.60	3.80	0.06	0.43	7.2	3.0	0.12	0.21	1.85	0.45	
29 - 66	4.80	3.80	0.03	0.18	6.0	1.0	0.10	0.37	2.55	0.30	
M 0 - 30	7.40	5.90	0.15	1.71	11.4	5.0	0.45	0.44	11.10	5.85	
30 - 60	7.20	5.80	0.11	1.02	9.30	2.0	0.65	0.58	10.88	5.10	

Soil depth (cm)	CEC (me/100 g)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density (g/cm^3)	Particle density (g/cm^3)	Porosity (%)
O 0 - 5	3.53	83	13	4	loamy sand	1.40 ± 0.14		
5 - 15	2.90	83	13	4	loamy sand	1.50 ± 0.08		
15 - 25	3.10	77	12	11	sandy loam	1.48 ± 0.05		
25 - 40	2.99	73	10	17	sandy loam	1.40 ± 0.08		
K 0 - 3	7.4	74.5	12.0	13.5	sandy loam			
3 - 29	6.5	64.1	12.8	23.1	sandy clay loam			
29 - 66	7.3	63.1	12.2	24.8	sandy clay loam			
M 0 - 30	45.00	17.00	39.00	44.00	clay	1.14	2.06	44.53
30 - 60	46.78	46.00	27.00	27.00	sandy clay loam	1.30	2.28	42.92

Methods

Soil properties at the three sites are shown in table 1. The Malang site (annual rainfall about 1800 mm) has a dark grey alluvial soil of high pH, high CEC and low P-status. Ketapang and Onne (annual rainfall about 2200 and 2400 mm, respectively) are ultisols: acid, low-activity loamy soils with low CEC and clay content increasing with depth. The Onne soil is remarkably rich in P.

Onne: Plots with leguminous cover crops for root observations were sown at IITA's high-rainfall substation at Onne (Port Harcourt), S.E. Nigeria in April 1985. The experimental site was mechanically cleared of forest and tree stumps more than 10 years before, and had been under continuous mechanized farming. Before the cover crops experiment was started, the area was covered by a natural grass fallow, which was cut regularly. Six species of leguminous (cover) crops were used (nomenclature following Allen and Allen, 1981): *Centrosema macrocarpum* Benth. (CIAT 5062), *Desmodium ovalifolium* Wall. ex Merr. (CIAT 3784), *Pueraria phaseoloides* (Roxb.) Benth., *Psophocarpus palustris* Desv., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer and *Vigna unguiculata* (L.) Walp.. In the experiment the effect of liming (CaCO3, 1 t/ha) was tested (Hairiah and Van Noordwijk, 1986). Samples of the root system were taken with a pinboard at 2, 5, 8 and 14 weeks after sowing. At the same dates aboveground biomass was sampled from three rows of 1 m length in each plot. Both samples were dried at 65 C and weighed.

Ketapang: Six species of leguminous cover crops were used: *Centrosema pubescens* Benth., *Pueraria phaseoloides* (Roxb.) Benth. (= *P. javanica* Benth.), *Calopogonium mucunoides* Desv., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer, *Crotalaria anagyroides* HBK, and *Crotalaria juncea* L. Samples of the root system were taken with a pinboard 8 months after planting (MAP), except for *Mucuna* which was taken at 5 MAP. Root patterns from washed pinboard samples were copied on a fine-grid paper.

Malang: The experiment (Hairiah, 1987) was carried out during the rainy season. The experimental site had been used as a sawah (paddy field) for lowland rice under traditional cultivation for a long period. Before the cover crops were planted the area was covered by *Imperata cylindrica* and some other weeds. Four species of leguminous cover crops were used: *Centrosema pubescens* Benth., *Mucuna pruriens* (L.) DC. var. *utilis* (Wall. ex Wright) Backer, *Crotalaria juncea* L., *Calopogonium mucunoides* Desv.; a maize crop fertilized with 125 kg N/ha, 45 kg P_2O_5/ha and 30 kg K_2O was used as control. The experiment was laid out as a randomized, complete design with 3 replications and a plot size of 6 x 2 m^2. Aboveground biomass was incorporated into the soil after 3 months and incubated for 2 weeks; biomass of maize in the control plot was removed and the soil was cultivated in the same way as the cover crop plots. Maize was sown in the second season; all plots received a basal application of P (as triple superphosphate) and K (as KCl) at a rate of 100 kg/ha each. Average rainfall was 2.4, 10.9 and 10.2 mm/day, respectively, for the three months in which the cover crops were grown, 8.6 mm/day for the incubation period and 3.5, 3.9 and 0.16 mm/day respectively for the three months of maize growth. Three randomly chosen plants from each plot were harvested at 2, 4, 8 and 13 weeks after planting; a mixed sample was made for N and P analysis. Washing roots from this soil proved to be difficult and maize root distribution was studied by mapping root distribution in a vertical and in a horizontal plane, 8 weeks after planting. In the same soil pits soil bulk density, available water content (between pF 2.5 and pF 4.2) and penetration resistance were measured.

Results and discussion

Onne

Figure 2 shows the shoot: root ratio, based on dry weights, for the six species, in the 14-week observation period. In the initial stages all species had a shoot: root ratio of 4, but later in *Vigna* and *Mucuna* root growth almost stopped while shoot dry weight continuously increased, leading to a shoot: root ratio of about 12. The other species maintained a shoot: root ratio of 4, or even decreased it to 2. At 14 weeks *Centrosema*, *Pueraria*, *Psophocarpus* had the greatest root dry weight and *Mucuna* and *Vigna* the greatest shoot production.

Mucuna and *Vigna* exhibited fast growth and early senescence, a low shoot: root ratio and a relatively high N-concentration in the shoots. These crops may benefit from the flush in N-mineralisation at the start of the rains through rapid uptake; they may be suitable as a short-term cover crop, releasing N from decaying biomass in the second part of the growing season. Their root development and consequently their chances of

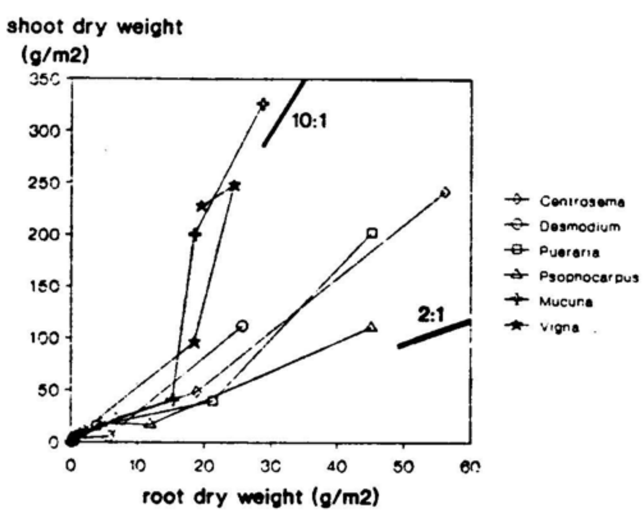

Figure 2. Shoot: root ratio of the six cover crops in Onne (Hairiah and Van Noordwijk, 1986).

TABLE 2 Biomass production, nutrient concentrations (on a dry-matter basis) and estimated total nitrogen content of cover crops, 14 weeks after planting in Onne (Hairiah and Van Noordwijk, 1986).

	N %	P %	K %	Ca %	Biomass t/ha	Sh.:root ratio	N-content kg/ha
Mucuna	3.0	0.23	1.23	0.21	3.42	14	110
Vigna veget.	1.8	0.22	1.00	0.21	2.30	10	45 }
,, pods	3.2	0.22	0.43	0.02	1.26	-	40 }
Centrosema	2.2	0.23	0.82	0.33	2.18	3.8	60
Pueraria	2.5	0.24	0.95	0.21	2.02	4.4	62
Psophocarpus	2.8	0.26	0.92	0.21	1.03	2.2	42
Desmodium	2.0	0.16	0.79	0.19	1.02	3.5	26

recovering leached nutrients are not impressive. *Pueraria* established itself relatively slowly but showed the best nodulation of the six species tested. *Centrosema* had poor nodulation, but developed the deepest root system (70 cm). *Psophocarpus* and *Desmodium* proved to be unsuitable under these conditions as they started slowly and had to be weeded frequently.

The liming treatment had little effect on root distribution and shoot growth (Hairiah and Van Noordwijk, 1986). Table 2 summarizes the N-contribution to the soil of above- plus belowground cover crop residues. No effort was made to separate N-fixation from soil N-uptake. For *Mucuna* the highest N-contribution to the soil was found, 110 kg/ha, and for *Desmodium* only 26; for the other species 40 to 60 kg/ha was found, assuming *Vigna* pods to be removed from the field.

Ketapang

Figure 3 shows the root development of cover crops at maximum growth as observed from pinboard samples. The root system of the six cover crops had the same overall shape with a vertical taproot and abundant branch roots in the topsoil; there were, however, marked differences in depth of root development (table 3). Remarks on the general performance of six cover crops are further summarized in table 3.

Species with creeping stems and fast initial development, as illustrated by *Mucuna* and to a lesser extent by *Calopogonium*, gave good initial weed control. The erect *Crotalaria* species do not directly cover the soil but it may shade out the weed *Imperata* in the longer run. *Mucuna* and *Calopogonium* had a shallow root system; their deepest roots reached a depth of about 50 cm; *Crotalaria* roots went deeper, with the deepest roots at about 80 cm. The other species developed too slowly to control all weeds initially; once established, however, they may be interesting because of a deep root development (*Centrosema*) or good nodulation (*Pueraria*). The rooting depth of *Centrosema* and *Pueraria* was about 80 cm.

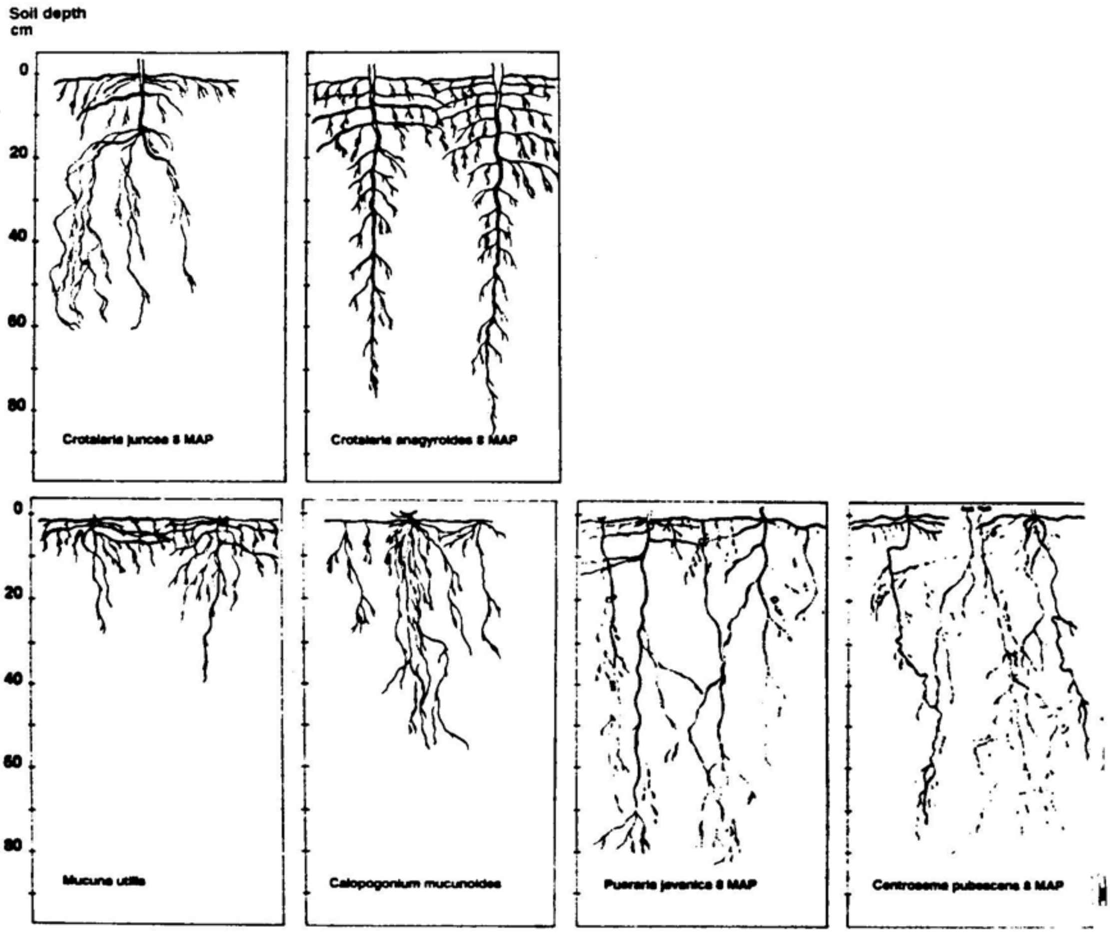

Figure 3. Root development of cover crops in Ketapang as observed from pinboard samples 8 months after sowing (Mucuna at 5 months) (Hairiah and Van Noordwijk, 1987).

TABLE 3. Observations on cover crop development in Ketapang S. Sumatera, sown in january after the start of the rains; form: c = creeping, e = erect; I.g. = initial growth: ++ = fast, + = good, 0 = slow; I4 and I8 = *Imperata* control at 4 and 8 months, respectively: ++ = good, + = limited and 0 = poor; r = *Imperata* regenerating.

Species	Form	Duration	I.g.	I4	I8	Root system & nodulation
Mucuna p. uti.	c	5 months	++	++	+(r)	shallow, many nodules
Calopogonium m.	c	perennial	+	++	0	rather shallow, few nod.
Crotalaria jun.	e	8 months	+	+	++	deep branch root, few nod.
Crotalaria ana.	e	perennial	+	+	++	deep tap root, few nodules
Centrosema pub.	c	perennial	0	0	+	shallow rhizomes, deep branc
Pueraria phase.	c	perennial	0	+	+	roots, nodules in subsoil too

Malang

In the experiment in Malang four cover crop species were used in the first part of the growing season, with a fertilized maize crop as the control. Table 4 shows the total N-contribution of the cover crops to the soil. It was calculated as N-concentration times measured above-ground dry weight of each crop; roots were included by using estimated shoot: root ratios. The highest N-concentration (on a dry-weight basis) was found in the *Mucuna* biomass, but the highest biomass production and N-contribution to the soil was obtained from *Crotalaria*. N-input in the control plot was calculated to be 125 kg/ha as fertilizer minus N-uptake, which was 44.5 kg/ha.

TABLE 4. N-contribution of legume cover crops to the soil.

	Dry weight (t/ha)	N-content (%)	C : N	shoot: root	N-contr. (kg/ha)	N : P
Centrosema pubescens	1.37	2.08	17	4	36	5.5
Mucuna utilis	3.62	2.85	20	12	71	4.7
Crotalaria juncea	9.08	1.87	23	4	198	6.0
Calopogonium mucunonoides	2.54	2.04	18	4	65	5.2

During the second season maize was grown as a test crop and a number of soil parameters were measured (Figure 4). Bulk density and soil penetration resistance were lower for the cover crop/maize plots than for the maize/maize plots in the zone 0 - 20 cm depth. The "available water" content, stored between pF 2.5 and 4.2, was also higher. These measurements were only performed in a single plot for each treatment, along with the root observations, so no statistical reliability can be given for the differences.

Table 5 shows that statistically significant effects between pre-cropping with various cover crops and maize gradually emerged. After four weeks (4 WAP), *Mucuna* as a pre-crop had a significant, positive effect on dry weight of maize; at 8 WAP *Crotalaria* as a pre-crop resulted in significantly higher maize biomass as well. At harvest time (13 WAP) all four cover crop plots gave a significantly higher grain yield than maize as a pre-crop; the *Mucuna* plots gave the best results, followed by the *Crotalaria* plots.

Figure 5 shows that the N and P concentrations in aboveground biomass of maize gradually decreased during the growing season. Only at 4 WAP, were differences in N-concentration between treatments apparent. The relatively high harvest index for N on the control plots (table 6) suggests that the control maize plants were N-limited, at least in the last part of the growing season. N-concentration in the grain did not differ between treatments (table 5), but control plants remobilized a larger part of their N-content to the grains. P-concentrations in maize tended to be high in *Mucuna* plots throughout and low in *Calopogonium* plots (Figure 5). The harvest index for P (table 6) suggests that maize following

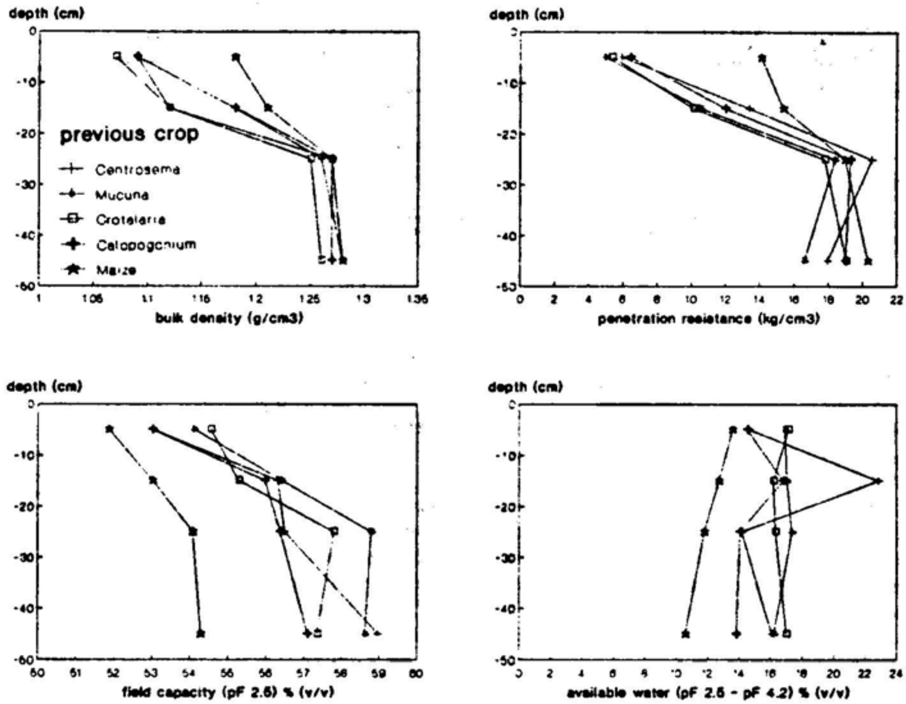

Figure 4. Bulk density, penetration resistance, field capacity and available water content of the soil of maize plots which had 4 different cover crops and maize as preceding crops.

TABLE 5. Dry weight of maize (second season) as influenced by preceding crop. Values followed by the same letter do not differ significantly (p=0.05).

Preceding crop	Dry weight of total biomass (t/ha) at 2	4	8	13 WAP	Grain dry weight	%N
Mucuna utilis	0.011a	0.027b	5.6c	14.7c	4.0d	1.6a
Crotalaria j.	0.006a	0.020a	4.6b	12.9bc	3.1c	1.7a
Calopogonium	0.007a	0.019a	2.8a	10.1b	2.4b	1.7a
Centrosema p.	0.008a	0.020a	2.5a	8.8ab	2.1b	1.6a
maize-control	0.007a	0.015a	2.5a	4.8a	1.4a	1.6a

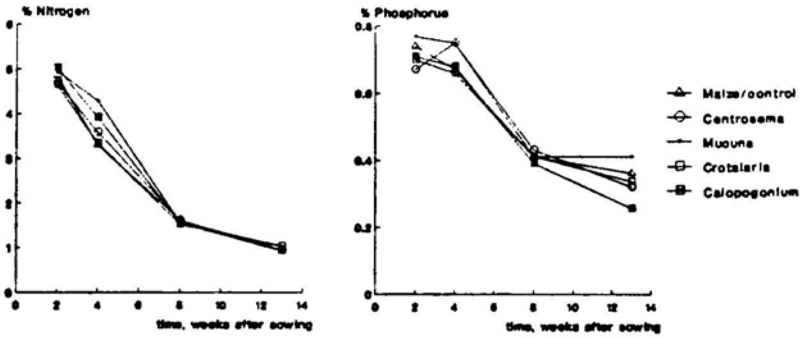

Figure 5. Nitrogen and phosphorus concentrations in aboveground biomass (N and P as of dry weight) of maize during the growing season.

Calopogonium and *Centrosema* was more P-stressed than maize on the other plots, including the control plots (which had received a P dressing in the first maize season as well).

Maize root distribution was observed 8 weeks after planting. The rooting pattern of maize following cover crops differed from that of maize after maize. The vertical root maps in figure 6 show that the *Crotalaria* plot gave the highest, and the control plots the lowest root density. In the control plots roots of neighbouring plant rows hardly intermingled. The horizontal root maps at a depth of 10 cm in figure 6 show that some space on the map of the control plot is still empty; empty spaces indicated more possibilities for nutrients leaching to deeper layers.

The fact that maize yields were more than doubled by a cover crop in the preceding season suggests that, in the absence of N-fertilizer, growing a non-food cover crop for half the year might even be profitable: it increased maize production per ha per year. There are several possible explanation for the positive yield effects of a preceding cover crop: increased N-supply, increased water storage, improved root development of the test crop, fewer weeds, pests and diseases.

In table 6 the N-balance of maize as affected by the preceding crop is given. The extra N-uptake by maize on a plot with a cover crop as the preceding crop is compared with the N-input from the first seasons crops. Excess N-uptake and calculated N-input were of the same magnitude, but the order of *Mucuna* and *Crotalaria* differed. *Crotalaria* gave the highest cover crop biomass and highest N-input, and resulted in the highest (second season) maize root density. Yet, *Mucuna* had an even stronger effect on maize production. Due to the relatively high C : N ratio of *Crotalaria*, about 23, a relatively slow decomposition may be expected. For *Mucuna* we assume either that the N-input was underestimated by neglecting N-release into the soil during the *Mucuna* growth, or that improved rooting made soil N from deeper layers available. Unfortunately no information was obtained on the amount of N fixed from the atmosphere and that taken up from the soil.

Yield effects on the maize through effects on weeds, pests or diseases could not be excluded, but no diseases were observerd, and weed

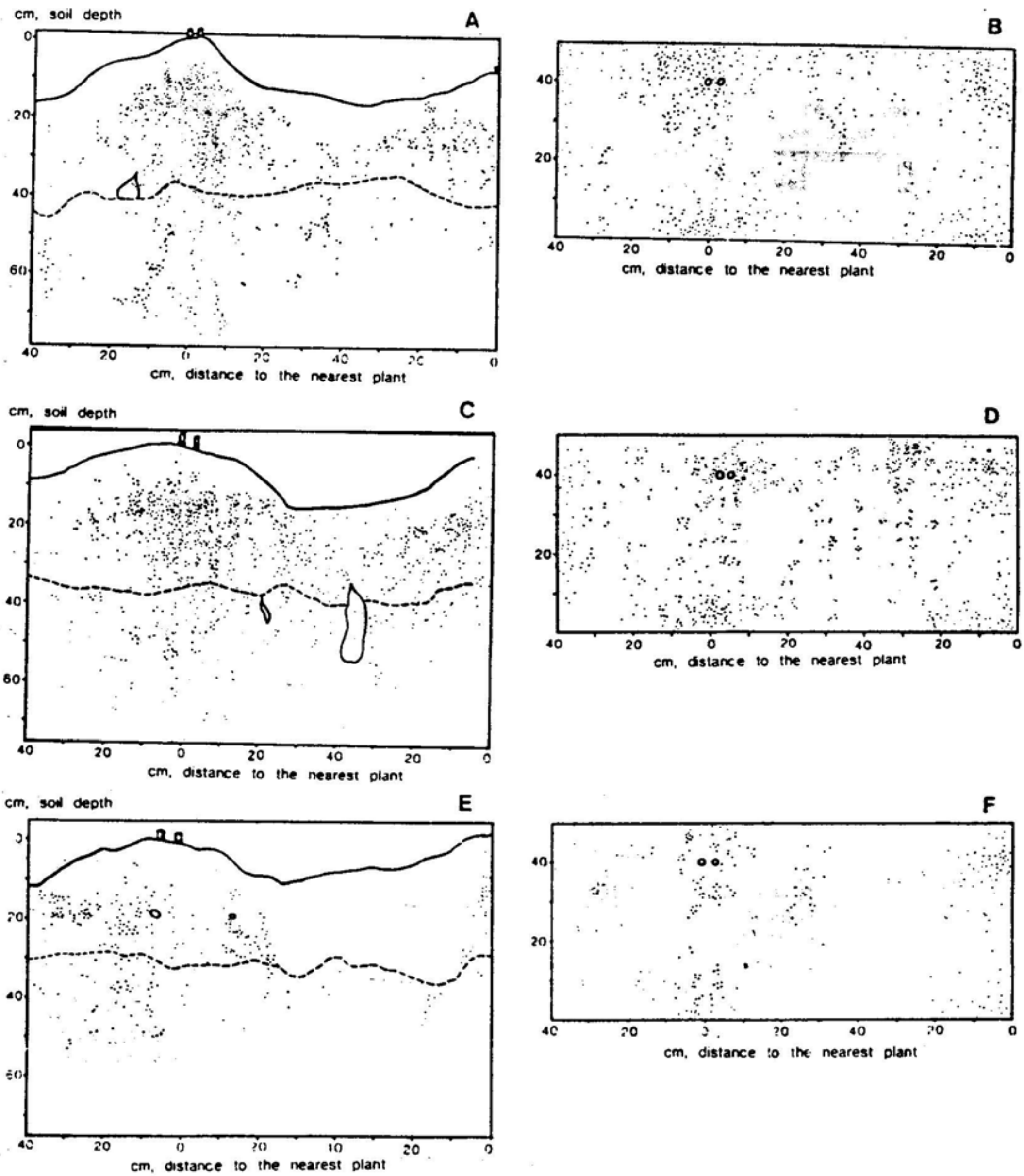

Figure 6. Distribution of maize roots on vertical (A,C,E) and horizontal (B,D,F) root maps, at 8 WAP, on plots with different preceding crops: *Mucuna* (A,B), *Crotalaria*(C,D) and maize (E,F).

TABLE 6. N-input from preceding crop, excess N-uptake relative to control plots and harvest indices (fraction of total N or P content or dry weight found in the grains at harvest), for maize in the second season.

Preceding crop	N-input kg/ha	Excess N-uptake	------Harvest index------ N	P	dry weight
Mucuna p. uti.	71	147	0.29	0.38	0.21
Crotalaria j.	198	121	0.28	0.37	0.19
Calopogonium	65	67	0.30	0.45	0.19
Centrosema p.	36	52	0.29	0.40	0.19
maize-control	80	0	0.33	0.38	0.23

levels were kept low in all plots. Positive yield effects on the maize may have resulted in part from improved water storage in the soil, especially in the final part of the maize growing season, with low rainfall. Such positive effects, which cannot be replaced by fertilizer supply, are relevant in high-input agriculture as well (Bouldin, 1988). The better rooting of maize following a cover crop may have been a combined result of a higher N-supply and improved soil physical conditions. In the second part of the growing season improved root development probably contributed to better use of water, stored in deeper layers, and hence to higher production.

Conclusions

Positive effects of cover crops in a crop rotation are not only confined to their N-contribution to the soil: weed control, improvement of soil physical conditions and improved root development of the food crops can be relevant as well. The choice of a cover crop for a particular cropping system should depend on the most important aspect. For the cover crops tested here the following conclusions can be drawn:
Mucuna grew fast and aged quickly on both the acid soils and on alluvial soil. It had a shallow root system with many nodules on the acid soils. On the alluvial soil it had the best yield effect on a subsequent maize crop.
Crotalaria grew fast on the acid soil in Lampung and on the alluvial soil at Malang. It had a deep and well-branched root system on the acid soil, with few nodules.
Pueraria established itself relatively slowly and showed the best nodulation of all species tested, on both acid soils.
Centrosema had a slow start on the acid soils as well as on alluvial soils; it had a deep and well-branched root system.

Mucuna and *Crotalaria* were shown to be the most suitable species as short-term cover crop in a rotation with maize. If *Mucuna* species with a deeper root system on acid soils could be discovered with a possible improvement of Al tolerance and/or better ability to penetrate dense soil layers, positive effects on following crops may even become greater.

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