ROOTS AS PART OF THE CARBON AND NITROGEN INPUT AND OUTPUT OF THREE TYPES OF CROPPING SYSTEMS ON AN ULTISOL IN NORTH LAMPUNG

Kurniatun Hairiah[1], Meine van Noordwijk[2] and Georg Cadisch[3]

[1]Fac. of Agriculture, Brawijaya University, Malang, Indonesia;
[2] ICRAF SE Asia, Bogor, Indonesia;
[3] Wye College, Univ. of London, UK;

ABSTRACT

Yields of annual food crops typically decline with time after conversion of forest (fallows) in the humid tropics, along with a declining soil organic matter content. Application of organic matter particularly in combination with inorganic fertilizers, may maintain a high crop production. However, the availability of organic materials such as (green) manure or crop residues is limited, while fertilizer use is often not within the financial possibilities of small farmers. Understanding the dynamics of C and N in such systems may help to understand the options for soil management. Three types of cropping systems were evaluated in 1994-1996 in Lampung i.e. cassava-based intercropping, hedgerow intercropping and legume cover crop rotations. The purpose of this presentation is (a) to quantify C-input and output from above ground and below ground of different cropping systems, (b) to measure a productivity index of different cropping systems as indicator of sustainability. In the cassava-based systems (CS 1 and 2) much more C was removed (6 Mg ha^{-1} year^{-1}) than in the other systems, while the amount returned to the soil was much smaller than in the other cropping systems. About 0.5 - 4.5 Mg ha^{-1} was returned to the plot as litter fall, green leaf and roots of cassava (CS1), and maize + rice residues (CS2) and about 5 - 7 Mg ha^{-1} has been transported out of the plot (as tuber and stems). The hedgerow intercropping (CS 3 and 4) gave a positive balance, as about 4.5 Mg ha^{-1} was returned to the plot as biomass pruning and crop residues and about 1.5 Mg ha^{-1} was removed out of plot as yield. The cover crop rotation (CS 5 and 6) gave a surplus C about 4 Mg ha^{-1} where 2 Mg ha^{-1} of C was returned to the plot as crop residues plus *Mucuna* (only the 2nd year) and Cowpea biomass, and about 1.1 Mg ha^{-1} was transported out plot. The hedgerow intercropping systems (CS 3 and 4) gave an N input of about 25 kg ha^{-1} year^{-1} returned to the soil, the balance was 55-60 kg ha^{-1} year^{-1} for the cover crop rotation systems (CS 4 and 5). The cassava based (CS 1 and 2) systems gave the highest negative N budget was about 200-275 kg ha^{-1} year^{-1} was removed out of the plot. This calculation on C and N budget may help to explain the decline of cassava yield during 3 years of cropping after slashing and burning the forest. The addition of N via N_2-fixation of leguminous was excluded from this calculation. Rice showed the highest C input (shoot + roots) about 3.5 Mg ha^{-1} year^{-1}.compared to *Flemingia*, mix *Peltophorum+Glirlcidia* and maize which gave input of about 2.75, 37.5, 0.6 Mg ha^{-1} year^{-1}. Roots as part of C input to soil contributes about 20 %, 37 %, 55% and 65 % for *Flemingia*, mix *Peltophorum+Gliricidia* , rice and maize, respectively The cassava monoculture and hedgerow intercropping systems showed the index of productivity (I_p index) was below 1.0, indicating that yields were insufficient. The cowpea grown in CS6 contributed more to the I_p than groundnuts, as it gave a good yield in two out of three years. This experiment provides further evidence for the trade-off between short term profitability and longer term sustainability of food crop production systems under these conditions. The intensive grain legume – cereal rotations at moderate fertilizer input levels appear to provide the best compromise.

Proc. Seminar Toward Sustainable Agriculture in Humid Tropics Facing 21st Century: 86 - 95
Bandar Lampung, Indonesia, September 27 – 28, 1999

INTRODUCTION

When the original forest vegetation is cleared on such soils by slash and burn methods, upland rice and maize can be grown, but yields decline rapidly and after a few years only cassava can still give acceptable yields (McIntosch and Effendi, 1979; Sitompul *et al.*, 1992). Application of organic matter particularly in combination with a inorganic fertilizers, may maintain a high crop production. However, the availability of organic materials such as manure or crop residues is limited, while fertilizer use is often not within the financial possibilities of small farmers. Maintaining crop residue may help considerably on acid soils, as the organic matter detoxifies part of the Al. Marschner *et al.* (1995) showed that annual application of crop residues as millet straw of 2 Mg ha^{-1} (as surface mulch) over a five years period doubled total dry matter of millet in Niger, West Africa. Provided that small amounts of P are used to overcome severe deficiency, maintenance of crop residues and the use of additional organic inputs from legume cover crops or regularly pruned trees may sustain production over an extended period. In farmer practice (Garrity *et al.*, 1997), however, declining yields often lead to (temporary) land abandonment and to fallow vegetation dominated by alang-alang (*Imperata cylindrica*).

Organic matter input can be based on aboveground and below ground input. Data on aboveground input mainly based on litter or returning plant residues to soil is well documented. Biophysicaly, the prunings of the hedgerow trees give a substantial organic input (4-12 Mg ha^{-1} of dry biomass for a 4 m hedgerow spacing; Hairiah *et al.*, (1992b). Field experiment in N. Lampung on C-input and output of different cropping systems showed that the cassava-based systems removed much more C (7 Mg ha^{-1} $year^{-1}$) than the other systems i.e. hedgerow intercropping and cover crop rotation systems. The amount returned (about 0.5 - 2 Mg ha^{-1}) to the soil was much smaller than in the other cropping systems. In the hedgerow intercropping system about 2.5 Mg ha^{-1} $year^{-1}$ was returned to the plot as biomass pruning and crop residues and about 1.5 Mg ha^{-1} $year^{-1}$ was removed out of plot as yield. In the cover crop rotation 2.6 Mg ha^{-1} $year^{-1}$ of C was returned to the plot as crop residues plus *Mucuna* (only the 2nd year) and cowpea bio-mass, and about 1.1 Mg ha^{-1} $year^{-1}$ was transported out from the plot.

Inputs of root tissue into soil environment can occur from losses of mucilage, sloughing of root tissues during root senescence, senescence of woody or fine roots, root tissue loss or damage due to soil biota grazing, and from root respiration Of all these processes , however, root mortality is generally assumed to contribute most to the formation of soil organic matter. The amount of C contributed to the soil by root mortality will depend on the amount of C compounds resorbed by the plant prior to senescence. The availability of data on C-input by roots into soil ecosystems in tropics is very limited. In this paper we will discuss on C-input based on measurement of root mortality in the field using minirhizotron.

On the basis of general sustainability criteria (Van der Heide *et al.*, 1992), the following issues appear to be crucial for sustainable crop production:

A. avoiding (re-) infestation by *Imperata* and/or the ability to control/reclaim;
B. maintaining soil organic matter and soil structure, avoiding erosion,
C. maintaining the nutrient balance, compensating for nutrient exports with farm products plus unavoidable losses,
D. achieving a reasonable yield per unit labour + external inputs.

The purpose of this presentation are:

- To quantify C-input and output from above ground and below ground of different cropping systems in N. Lampung.
- To measure grain yield of maize of different cropping systems.

MATERIALS AND METHODS

Plot history and land preparation

The experiment was started in November 1994 at the start of the rainy season. Data are reported here for three cropping seasons, up to the cassava harvest of August 1997. The plot was laid out in an existing *Imperata* fallow on an acid ultisol of low fertility. This plot was formerly used as an experimental plot (cassava-based cropping systems for 2 years in 1990-1991) described by Sitompul *et al.* (1992) and had been invaded by *Imperata* for 3 years prior to the start of current experiment. *Imperata* was slashed manually and all biomass was removed from the land, a week later all plots were sprayed with Glyphosate (Round up, 2 kg ha^{-1}) and the soil was lightly hoed till about 5 cm depth. To homogenize the plot, *Mucuna* was planted for all plots with a plant distance 50 x 50 cm; unfortunately growth performance of *Mucuna* was very heterogeneous due to a long dry season. In an effort to reduce subsequent variability of soil fertility, all aboveground biomass of *Imperata* and *Mucuna* was removed from the experimental plots. As *Mucuna* failed to effectively cover the land, *Imperata* returned rapidly; all plots were sprayed once more with Round-up at 2 weeks before planting.

A composite soil sample was collected from the 0-5 and the 5-15 cm soil depth layers (Table 1) before treatments were implemented. The organic matter content of the soil was lower than the reference C_{ref} value to be expected for a soil of similar texture and pH under forest cover in Sumatra (Van Noordwijk *et al.*, 1997b), but the C_{org}/C_{ref} ratio (0.8 – 0.9) was not as low as found for land under a prolonged cassava/*Imperata* cycle in a recent survey in Sumatra (Hairiah and Van Noordwijk, unpublished results; for the top 5 cm C_{org}/C_{ref} can drop to 0.55). Soil pH and ECEC are similar to when the land was first cleared from forest (Van der Heide *et al.*, 1992). Al saturation was 31% and 19% for the 0-5 and 5-15 cm layer, respectively.

Table 1. Soil chemical properties at the beginning of experiment at 0-5 and 5-15 cm depth (averaged over 4 blocks); the reference value C_{ref} for C_{org} is based on a regression of the C_{org} in the top 10 cm of forest soils on soil texture and pH (Van Noordwijk *et al.* 1997b)

Soil parameters:	Soil depth (cm)	
	0 - 5 cm	5 - 15 cm
pH_{H2O}	5.33	5.43
pH_{KCl}	3.90	4.10
C-org, %	2.55	2.13
Tot. N, %	0.13	0.12
P-Bray II, mg kg^{-1}	10.0	11.0
K, $cmol_c$ kg^{-1}	0.17	0.15
Na, $cmol_c$ kg^{-1}	0.33	0.34
Ca, $cmol_c$ kg^{-1}	2.50	2.22
Mg, $cmol_c$ kg^{-1}	0.95	1.15
Al + H, $cmol_c$ kg^{-1}	1.79	0.92
ECEC $cmol_c$ kg^{-1}	5.74	4.78
Sand, %	66.3	64.0
Loam, %	16.0	17.0
Clay, %	17.7	19.0
Texture	Sandy loam	Sandy loam
C-reference, C_{ref}	2.75	2.72
C_{org} / C_{ref}	0.93	0.78

Experimental design

The four blocks of the experiment coincided with those of the previous cassava experiment, maintaining the footpaths between blocks. Plots within blocks were randomly allocated to three main types of cropping system, with two variants each as split-plots, with N fertilizer (0 and 60 kg N ha^{-1} yr^{-1}) as split-split plot factor. Plot size was 12 x 13 m^2.

Comparisons between the cropping systems were mainly based on the yields of the upland rice + maize in the first season of systems 1B, 2 and 3, on the second seasons crops (systems 2 and 3), and on the productivity index (sum of all crop yields relative to their crop specific targets), as before (Van der Heide *et al.*, 1992).

The cropping calendar has been described in Hariah *et al.* (*submitted*) (Table 2) was adjusted to the specific rainfall patterns of each year. Short-season cover crops could be grown only in 1 (*Mucuna*) or 2 (Cowpea) of the three years. For the first season food crops, an 80-20% mixture of upland rice and maize was used, as is common farmer's practice. Maize is a good N indicator crop, but sole cropping with maize in the cassava system proved to be unsustainable in the previous experiment 1 (Sitompul *et al.*, 1992).

Table 2. Cropping calendar applied for six cropping systems (CS); + indicates intercropping and - sequential crops

CS	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1	Cassava --									- *Mucuna*		
2	Upland rice + maize---------									- Cowpea		
3	Hedgerows of *Gliricidia* & *Peltophorum* pruned at X											
	Upland rice + maize				Groundnut			- tree fallow + strip cowpea				
4	Hedgerows of *Flemingia congesta* pruned at X											
	Upland rice + maize				- Groundnut			- tree fallow + strip cowpea				
5	Upland rice + maize				- Groundnut			- *Mucuna* cover crop				
6	Upland rice + maize				- Groundnut			- Cowpea				

Planting material

For cassava local planting material was collected from the neighbouring village Negeri Besar and stem cutting of 0.2 m were planted with a plant distance of 1 x 1 m for cassava monoculture and 2 x 0.5 m for intercropping system. Maize (var. Arjuna) and rice (var. Serendah) were intercropped with a plant distance of 1 x 0.5 m and 0.5 x 0.1 m, with 3 and 5 seeds per hole, respectively.

After harvesting rice (end of April) groundnut seeds (local variety) were sown with 2 seeds per hole with plants distance of 0.25 x 0.25 m. At the end of the rainy season (June) directly after harvesting groundnuts, *Mucuna pruriens* var *utilis* or cowpea (*Vigna unguiculata* var.

IT-816) were planted at plant distance 0.5 x 0.25 m. *Mucuna* failed to establish in 1996 and 1997, cowpea failed in 1997.

Three hedgerow tree species were planted in October 1994, *Gliricidia sepium, Peltophorum dasyrrachis*, and *Flemingia congesta*. *Gliricidia* was propagated from stem cuttings of locally available trees; *Peltophorum* seedlings were collected from secondary forest regrowth surrounding the experiment and planted in a polybag 3-4 months before transfer to the field; *Flemingia* was planted directly from seedlings raised in polybags (seeds were obtained from UD Sri Bhaearata, Blitar-East Java). *Gliricidia* and *Peltophorum* were planted alternately within single rows, using a plant distance 4 x 0.5 m and a the plants population became 10.000 per ha. *Flemingia* was planted with plant distance 4 x 1 m.

Pruning of the hedgerow trees was started in October 1995 (before planting food crops), and later pruning was done whenever deemed necessary. The pruning biomass was weighed freshly, returned and spread evenly into plot. Biomass subsample was taken to estimate the biomass dry weight, ground and analyzed for total C, N and P concentrations (Table 3).

Table 3. Chemical properties of hedgerow tree prunings; numbers followed by different letters are significantly different ($P<0.05$); the *Peltophorum* and *Gliricidia* trees were growing in a mixed hedgerow (Hairiah *et al.*, 1999, *submitted*)

Species	DW, Mg ha^{-1} per pruning time		Tot C, %		Tot N, %		Tot P, %	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Peltophorum	0.73b	0.25b	34.6b	40.6a	1.65c	0.45b	0.25b	0.08a
Gliricidia	0.38c	0.27b	38.5a	42.5a	3.08a	0.97a	0.43a	0.19a
Flemingia	1.00a	0.66a	38.6a	41.2a	2.48b	0.53b	0.41a	0.11a

Fertilizer and maintenance

N fertilizer (as urea) was given into plot according to the treatment, and it was broadcast twice i.e. at planting time and one month after planting. All plots received 60 kg ha^{-1} P_2O_5 (TSP) and 60 kg ha^{-1} K_2O (KCl) as basal fertilizer, which was applied before planting of maize/rice and groundnut. Weeding was done manually, pest control was done whenever required by spraying a mix of Sevin 85E (60 ml /15 l water), Azodrin (60 ml/15 l water) and Basudin (60 ml/15 l water).

Grain yield of food crops was measured at physiological maturity by harvesting above ground (gram per unit area), and separated between vegetative and generative parts. Sub samples were taken, dried in the oven at 80^0 C for 2 days, grounded and analyzed their C and N content.

Soil samples was collected at the beginning of rainy season (October) form every plot at 0 - 5 and 5 -15 cm depth for pH, total C and N measurement.

Roots observation

Images from roots growing along an obervation surface were obtained with a modified endoscope system, using simple inflatable minirhizotrons as developed in the 1980's at the AB-DLO, Haren, the Netherlands (Gijsman *et al.* , 1991). M inirhizotrons were inserted in 5 treatment CS 1, CS 2, CS3, CS 4, CS 6, 3 replication of each, to an effective depth of 60 cm. Roots were observed monthly and a total of 18 sets of photographs (representing a depth of 0-10,10-20, 20-30, 30-40 and 40-60 cm, respectively) from the period December 1995 through March 1996 was used for the current analysis. The images were assessed as a time series and all changes (+ or -) in root intersections with a standard grid of lines were recorded. From these data the cumulative pattern of root growth was derived and root disappearance was expressed as fraction of cumulative root growth.

Statistical analyses

Results were analyzed with AN(C)OVA (analysis of (co)variance) by using the GENSTAT 5 computer program (Payne *et al.*, 1987)..

To measure sustainability of different cropping systems, Van der Heide *et al.*, (1992) introduced an index of production (IP) to combine the yield of various crops as follows:

$$I_P = \frac{1}{n}\sum_{i=1} Y_i / T_i$$

where,

Y_i = actual yields

T_i = target yields of crops, based on local input and output prices.

Based on 1997 prices we used as values of T_i: cassava fresh tuber 25 Mg ha^{-1}, maize grain 5 Mg ha^{-1}, rice grain 2.5 Mg ha^{-1}, groundnut and cowpea 2 Mg ha^{-1}. An I_p index consistently above 1.0 indicates an acceptable, sustained crop yield. The I_p index can be used for evaluating mixed cropping systems, without using a monoculture yield for reference as in a 'relative yield total' or 'land equivalent ratio' calculation.

RESULTS AND DISCUSSION

Input and output of Carbon and Nitrogen

Figure 1 shows the amount of C removed from an returned to the soil in the various cropping systems. In the cassava-based systems (CS 1 and 2) much more C was removed (6 Mg ha^{-1} year^{-1}) than in the other systems, while the amount returned to the soil was much smaller than in the other cropping systems. About 0.5 - 4.5 Mg ha^{-1} was returned to the plot as litter fall, green leaf and roots of cassava (CS1), and maize + rice residues (CS2) and about 5 - 7 Mg ha^{-1} has been transported out of the plot (as tuber and stems). The hedgerow intercropping (CS 3 and 4) gave a positive balance, as about 4.5 Mg ha^{-1} was returned to the plot as biomass pruning and crop residues and about 1.5 Mg ha^{-1} was removed out of plot as yield. The cover crop rotation (CS 5 and 6) gave a surplus C about 4 Mg ha^{-1} where 2 Mg ha^{-1} of C was returned to the plot as crop residues plus *Mucuna* (only the 2nd year) and Cowpea biomass, and about 1.1 Mg ha^{-1} was transported out plot.

By excluding roots as C-source, hedgerow intercropping systems (CS 3 and 4) gave a surplus C input to soil about 2.5 Mg ha^{-1} was returned to the plot as biomass pruning and crop residues and about 1.5 Mg ha^{-1} was removed out of plot as yield. The cover crop rotation (CS 5 and 6) gave a surplus C about 1.5 Mg ha^{-1} where 2.6 Mg ha^{-1} of C was returned to the plot as crop residues plus *Mucuna* (only the 2nd year) and Cowpea biomass, and about 1.1 Mg ha^{-1} was transported out plot.

All of cropping systems tested gave a negative N input, the hedgerow cropping systems gave the lowest negative balance. The hedgerow intercropping systems (CS 3 and 4) gave an N input of about 25 kg ha^{-1} year^{-1} returned to the soil, the balance was 55-60 kg ha^{-1} year^{-1} for the cover crop rotation systems (CS 4 and 5) (Figure 2). The cassava based (CS 1 and 2) systems gave the highest negative N budget was about 200-275 kg ha^{-1} year^{-1} was removed out of the plot. This calculation on C and N budget may help to explain the decline of cassava yield during 3 years of cropping after slashing and burning the forest. The addition of N via N_2-fixation of leguminous was excluded from this calculation.

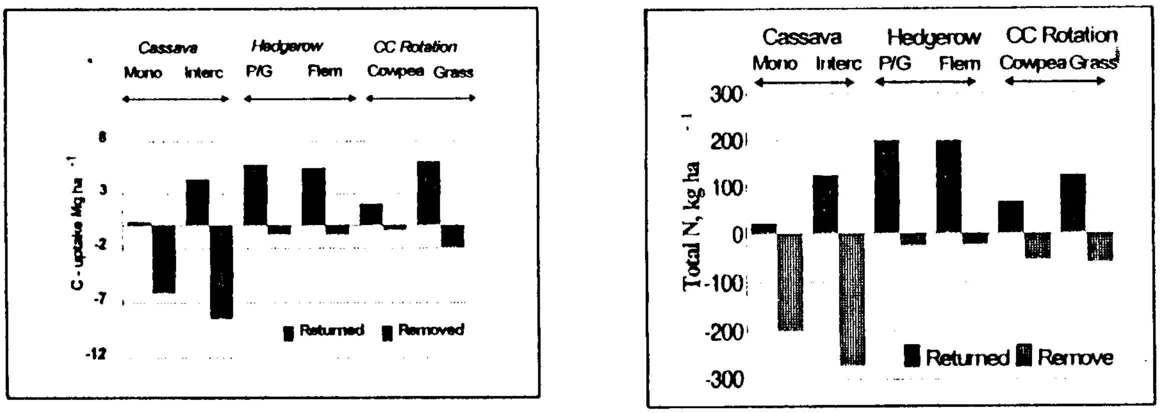

Figure 1. Carbon and Nitrogen balance of different cropping systems.

Roots as part of carbon and nitrogen input

Roots contribute quite a large amount of biomass and C to soil which varies between species. The amount of C input come from roots is depending on root biomas and root turn over. Rice showed the highest C input (shoot + roots) about 3.5 Mg ha^{-1} compared to *Flemingia*, mix *Peltophorum+Gliricidia* and maize which gave input of about 2.75, 37.5, 0.6 Mg ha^{-1}. Roots as part of C input to soil contributes about 20 %, 37 %, 55% and 65 % for *Flemingia*, mix *Peltophorum+Gliricidia* , rice and maize, respectively (Figure 3).

Crop yields and index of productivity (I_p)

Sustainability of cropping systems was estimated by calculating the index of productivity (I_p), based on marketed products, clearly differentiated the cropping systems (Table 4): for the cassava monoculture and hedgerow intercropping systems the index was clearly below 1.0, indicating that yields were insufficient (hedgerow intercropping) and/or declining (cassava monoculture). The cassava intercropping system as well as the rice/maize grain legume rotations met the yield expectations as expressed in the I_p index, and maintained or increased productivity

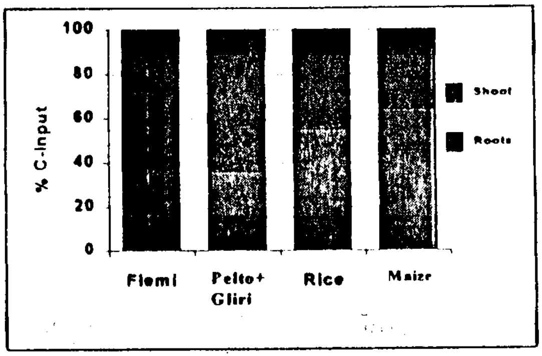

Figure 2. Roots of *Flemingia, Peltophorum+ Gloricidia,* rice and maize as part of Carbon input to soil.

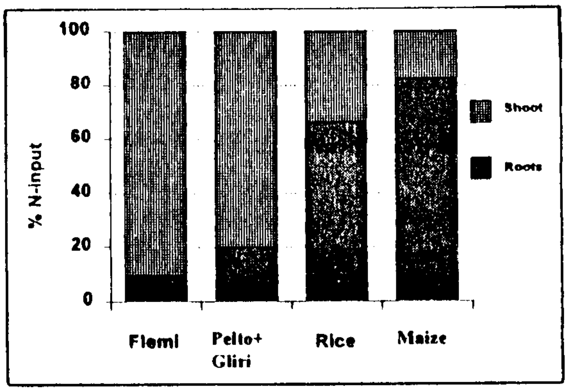

Figure 3. Roots of *Flemingia, Peltophorum+ Gliricidia,* rice and maize as part of Nitrogen input to soil.

within the three cropping years. The cowpea grown in CS6 contributed more to the I_p than groundnuts, as it gave a good yield in two out of three years.

The highest production index (I_p) was obtained under cereal-grain legume crop rotations systems (especially CS6) and the cassava – rice intercropping system (CS2, Table 4). In the intercropped cassava the rice crop during the wettest part of the year, while cassava is still small and its roots shallow, captured nitrogen that was probably lost by leaching from the monoculture. The rice residues left on the soil surface supplied N to the cassava when it needed them, and this effect probably made up for any negative impacts of competition. Even this cassava based system, however, is not likely to be sustainable, as it had a negative N balance (Fig. 3) and was depleting N_{tot} of the soil (Table 4).

Overall this experiment provides further evidence for the trade-off between short term profitability and longer term sustainability of food crop production systems under these conditions. The intensive grain legume – cereal rotations at moderate fertilizer input levels appear to provide the best compromise.

Table 4. Index of productivity (I_p) of different cropping systems over 3 years time of observation.

Crops	CS1	CS2	CS3	CS4	CS5	CS6
Cassava	0.57	0.74	-	-	-	-
Maize	-	0.05	0.05	0.06	0.12	0.09
Rice	-	0.58	0.57	0.47	0.94	0.97
Groundnuts	-	-	0.08	0.09	0.13	0.12
Cowpea	-	-	0.04	0.08	-	0.35
IP	0.58	1.37	0.74	0.71	1.19	1.53
Average	0.98		0.73		1.36	

ACKNOWLEDGEMENTS

The experiment in Lampung was financially supported by a grant from the European Union (EU TS3*-CT94-0261).

REFERENCES

Garrity, D.P., Soekardi, M., Van Noordwijk, M., de la Cruz, R., Pathak, P.S., Gunasena, H.P.M., van So, N., Huijun, G. and Majid N.M., 1997. The *Imperata* grasslands of tropical Asia: area, distribution and typology. Agroforestry Systems 36: 3-29.

Hairiah K., Utomo W.H. and Van der Heide J. 1992a. Biomass production and performance of leguminous cover crops on an ultisol in Lampung. Agrivita 15: 39-44.

Marschner H, Rebafka F P, Hafner H and Buerkart A, 1995. Crop residue management for increasing production of pearl millet on acid sandy soil in Niger, West Africa. In: Date RA, Grundon N J, Rayment G E, Probert M E (eds) Proc. 3rd Intern. Symp. Plant - soil interactions at low pH: Principles and management. Kluwer Academic Publ. the Netherlands. p 767-770.

McIntosch J L and Effendi S, 1979. Soil fertility implications of cropping patterns and practices for cassava. In: Weber L, Nestel B and Campbell M (eds). Intercropping with cassava. Proc. Intern. Workshop Trivandum, India. IDRC, Ottawa, Canada. pp 77-85.

Payne R W, Lane PW, Ainsley A E, Bicnell K E, Digby P G N, Harding S A, Verrier P J, White R P, 1987. Genstat 5 reference manual. Clarendon Press, Oxford. 749 pp.

Sitompul S M, Setijono S, Van der Heide J, Van Noordwijk M, 1992. Crop yields and sustainability of cassava-based cropping system on an ultisol in N.Lampung. Agrivita 15 (1): 19-28.

Van der Heide J, Setijono S, Syekhfani MS, Flach E N, Hairiah K, Ismunandar S, Sitompul SM and Van Noordwijk M 1992. Can low external input cropping systems on acid upland soils in the humid tropics be sustainable ? Backgrounds of the Unibraw/IB Nitrogen management project in Bunga Mayang (Sungkai Selatan, Kotabumi N.Lampung, S. Sumatera, Indonesia). Agrivita 15 (1): 1-10.

Van Noordwijk, M., Sitompul S.M., Hairiah, K., Listyarini, E. and Syekhfani, M. 1995. Nitrogen supply from rotational or spatially zoned inclusion of leguminosae for sustainable maize production on an acid soil in Indonesia. In: R.A. Date, N.J. Grundon, G.E. Rayment and M.E. Probert (eds.) Plant-Soil Interactions at Low pH: Principles and Management. Kluwer, Dordrecht. pp 779-784.

Van Noordwijk, M., Hairiah, K., Partoharjono, S., Labios, R.V. and Garrity, D.P., 1997a. Sustainable food-crop based production systems, as alternative to *Imperata* grasslands? Agroforestry Systems 36: 55-82.

Van Noordwijk, M., Woomer P., Cerri C., Bernoux, M. and Nugroho, K., 1997b. Soil carbon in the humid tropical forest zone. Geoderma 79: 187-225.