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Crop yield, C and N balance of three types of cropping systems on an Ultisol in Northern Lampung

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Abstract

Three types of cropping systems, cassava-based intercropping, hedgerow intercropping and legume cover crop rotations, were evaluated in 1994–1997 in Northern Lampung, Sumatra. The purpose of this experiment was to quantify the C and N flows returned within and transported out of plots and crop yields of different cropping systems.

Cassava-based systems were not stable and yields declined over time. Intercropping cassava with rice increased cassava fresh tuber weight by 5–48% compared to the monocropping system. The hedgerow intercropping gave lower maize, rice, groundnut and cowpea yields than could be obtained in a crop rotation with legume cover crops. Maize grain yields in the 80–20 rice/maize mixture were about 0.4 Mg ha^{-1} in the rice – groundnut rotation and about half as much when intercropped with cassava or hedgerows. Rice yields intercropped with cassava or with hedgerows were about 1 Mg ha^{-1} less in year 2 and 3 than those grown in rotation with groundnut. The rice yield in the first cropping season was only about 1 Mg ha^{-1}, but in the second and third year yields in the rice – legume rotation increased to around 2 and around 3 Mg ha^{-1}, respectively. This increase occurred despite a decline in soil organic matter content.

The cassava-based systems removed much more C (7 Mg ha^{-1} yr^{-1}) than the other systems, while less was returned (about 0.5–2 Mg ha^{-1}) to the soil. In the hedgerow intercropping system about 2.5 Mg C ha^{-1} yr^{-1} was returned to the plot as biomass pruning and crop residues and about 1.5 Mg C ha^{-1} yr^{-1} was removed from the plot as yield. In the cover crop rotation 2.6 Mg ha^{-1} yr^{-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} yr^{-1} was removed from the plot. The hedgerow intercropping systems gave an N surplus of about 15–50 kg ha^{-1} yr^{-1} returned to the soil; while the balance was 10–20 kg ha^{-1} yr^{-1} for the cover crop rotation systems and the cassava-based systems showed a negative N budget of about 60 kg ha^{-1} yr^{-1}.

Keywords: Carbon and nitrogen balance, hedgerow intercropping, cover crop rotation, cassava-based systems, Ultisol.

Introduction

On acid infertile soils such as Ultisols in the humid tropics the efficiency of nutrient use is generally low due to a combination of high leaching rates and shallow root development of annual food crops (Van Noordwijk *et al.* 1996a). 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 & Effendi, 1979; Sitompul *et al.*, 1992). Application of organic matter particularly in combination with 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. Thus in normal practice, declining yields often lead to (temporary) land abandonment and to fallow vegetation dominated by alang-alang, *Imperata cylindrica* (Garrity *et al.*, 1997).

Purely crop-based production systems have little chance to be sustainable under upland conditions prone to *Imperata* infestation (Van Noordwijk *et al.*, 1997a). Intensive relay/intercropping systems can keep the grass out for a number of years (3–5), provided that small amounts of phosphorus are used to overcome severe P deficiency and especially where leguminous cover crops are included in the crop cycle. 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 land; b) maintaining soil organic matter and soil structure and avoiding erosion, c) maintaining the nutrient balance and compensating for nutrient exports with farm products plus unavoidable losses, and d) achieving a reasonable yield per unit labour and external inputs.

Cassava is a major component of these cropping systems for acid upland soils. It serves both as a staple food for the poorest part of the rural population in transmigration areas and as an industrial crop. Extensive cassava production heavily infested by *Imperata* with yields of only 5–10 Mg ha^{-1} of tuber is still considered worthwhile in Lampung, Sumatra.

In many areas in South East Asia, researchers have attempted to use the hedgerow intercropping concept to maintain or improve productivity of crop land, with mixed results on the biophysical side, and often low farmer adoption rates. It has been recognized over time that the adoption of hedgerow farming reduces the labour requirement for land clearing and weeding (Akobundo *et al.*, 1995; Anoka *et al.*, 1991). This may be a more important reason for farmer adoption than increases in the production of staple food crops (Fischer, 1995). The prunings of the hedgerow trees give a substantial organic input of 4–12 Mg ha^{-1} of dry biomass for a 4 m hedgerow spacing (Hairiah *et al.*, 1992b). They also introduce nutrients, from N_2 fixation (Hairiah *et al*, 2000), or from nutrients captured below the crop root zone as well as from the crop root zone itself (Rowe *et al.*, 1999). Analysis of the tree-soil-crop interactions in this system showed clear positive effects of mulch on soil characteristics, but competition for light (unless a very rigorous and time consuming pruning regime is maintained), water (in dry periods) and/or nutrients often outweighs the advantages (Van Noordwijk, 1996c). Data from the first five years of a long term experiment in North Lampung with several legume hedgerow trees showed that the highest maize production within alleys was obtained in hedgerow intercropping with *Peltophorum dasyrrachis* (previously wrongly identified as *P. pterocarpum*) and in combination with *Gliricidia sepium* (Hairiah *et al.*, 1992b; Van Noordwijk *et al.*, 1995). These two trees are also the strongest species as regards long term pruning tolerance (>10 years). In a separate experiment *Erythrina orientalis* and *Calliandra calothyrsus* died back after about 3 and 6 years, respectively, unpublished data).

Although farmers are generally aware of the positive impacts of leguminous cover crops on subsequent food crops, green manure cover crops are not used in annual food crop rotations on small farms. Grain legumes, however, are popular. Soybean was widely grown in the initial stages of the resettlement project in northern Lampung (Van Noordwijk *et al.*, 1996b), but diseases and declining soil fertility have considerably reduced its scope. Giller *et al.* (1994) showed that soybean may fix 70–87% of its N content or 26–188 kg ha^{-1} and cowpea may fix 32–76% of its N or 47–201 kg ha^{-1}. For these crops, however, the N-harvest index is 60–90% (22–194 kg ha^{-1}) and 31–70% (45–185 kg ha^{-1}), respectively. This means that on balance no N is added to the soil for subsequent crops. On the other hand groundnut, especially varieties with a relatively low N harvest index, can have a substantial positive residual effect on subsequent grain crops (McDonagh *et al.*, 1993, Nirmalawati *et al.*, 1996).

In earlier experiments in Lampung (Van der Heide *et al.*, 1992), several different variants of three types of cropping systems were evaluated: cassava-based intercropping (Sitompul *et al.*, 1992, Van Noordwijk & Purnomosidhi 1992), legume cover crop rotations (Hairiah *et al.*, 1992a, Utomo *et al.*, 1992) and hedgerow intercropping (Hairiah *et al.*, 1992b, Van Noordwijk *et al.*, 1995). A direct comparison between these systems was not possible, as they were tested in separate experiments. The experiment reported herein is part of the Biological Management of Soil Fertility (BMSF) project (Van Noordwijk *et al.*, 1996a), designed to obtain a direct comparison of the most promising versions of three types of food-crop production systems in one experiment to test the following hypotheses: i) cropping systems with relatively deep-rooted components with a high N demand during the main leaching season can reduce N leaching and maintain long term soil productivity, ii) addition of 'maintenance' amounts of P fertilizer together with maximum use of crop residues can sustain crop productivity on acid soils in production systems with a large share of grain legumes and acid-soil tolerant crop varieties, iii) hedgerow intercropping can provide long term benefits in maintaining soil productivity at acceptable crop yield reduction due to competition, and iv) in cassava-based production systems yields can not be maintained with a 'low external input' approach.

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 experiment was laid out in an existing *Imperata* fallow on an acid soil of low fertility classified as Grossarenic Kandiudult (Van der Heide *et al.*, 1992). This site 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 the 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 to about 5 cm depth. To reduce variability of soil fertility in the plot, *Mucuna* was planted for all plots with a plant distance 50 × 50 cm; unfortunately growth performance of *Mucuna* was very heterogeneous due to a long dry season. In an effort to further reduce variability of soil fertility, all aboveground biomass of *Imperata* and *Mucuna* was removed from the experimental area and plots were sprayed once more with round-up 2 weeks before planting. A composite soil sample was collected from 0–5 and 5–15 cm soil depth layers (Table 1) before treatments were implemented. The organic matter content of the soil was less 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 & Van Noordwijk, unpublished results; for the top 5 cm C_{org}/C_{ref} can drop to 0.55). Soil pH and ECEC were 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 the 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-BrayII, 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
Silt, %	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 (CS), with two variants (A, B) each (Table 2) as main-plots, with N fertilizer (0 and 60 kg N ha^{-1} yr^{-1}) as sub plot factor. Plot size was 12 × 13 m^2. Comparisons between the cropping systems were mainly based on the yields of the upland rice + maize in the first season of CS-1B, CS-2 and CS-3, on the second season's crops (CS-2 and CS-3), and on the productivity index (sum of all crop yields relative to their crop specific targets; Van der Heide *et al.*, 1992).

The cropping calendar (Table 2) was adjusted to the specific rainfall patterns of each year. Short-season cover crops could be grown only on CS-1 (*Mucuna*) or CS-2 (cowpea) of the three years. For the first season's food crops, a mixture of 80 % upland rice and 20 % 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 a previous experiment (Sitompul *et al.*, 1992).

Planting material

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

In cropping systems 2 and 3 after harvesting rice (end of April) groundnut seeds

Table 2. Cropping calendar applied for three main cropping systems (CS 1–3) and two variat (A+B); + indicates intercropping and – sequential crops.

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

(*Arachis hypogaea*, local variety Mahesa) were sown with 2 seeds per hole with planting distance of 0.25 × 0.25 m. At the end of the rainy season (June) directly after harvesting groundnuts, *Mucuna pruriens* var *utilis* (CS 3A, 1A) or cowpea (*Vigna unguiculata* var. IT-816) (CS 1B, 2A+B, 3B) were planted at a plant distance of 0.5 × 0.25 m. *Mucuna* failed to establish in 1996 and 1997, cowpea failed in 1997.

Three hedgerow tree species in CS 2 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 being transfered to the field; *Flemingia* was planted directly from seedlings raised in polybags (seeds were obtained from UD Sri Bharata, Blitar-East Java). *Gliricidia* and *Peltophorum* were planted alternately within single rows, using a plant distance of 4 × 0.5 m and hence a tree population of 5,000 per ha. *Flemingia* was planted with a plant distance of 4 × 1 m. Pruning of the hedgerow trees was started in October 1995 (before planting food crops), and later pruning was done whenever deemed necessary to avoid excessive competition with crops. The pruning biomass was freshly weighed, subsampled and the remainder returned by spreading evenly onto the plot. Biomass subsamples were taken from leaves and stems materials to estimate their dry weight, then ground and analyzed for total C, N and P concentrations (Table 3).

Fertilizer and maintenance

N fertilizer (60 kg N ha^{-1} as urea) was applied to the assigned sub-plots by broadcasting twice i.e. half at planting time and another half at 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).

Evaluations and statistical analyses

Grain yield of food crops was measured at physiological maturity and plant materials were separated between vegetative and generative parts. Sub samples were taken

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

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

(the remainder was returned to the plots), dried in the oven at 80°C for 2 days, ground and analyzed for their C and N content. Soil samples were collected at the beginning of the rainy season (October) from every plot at 0–5 and 5–15 cm depth for pH, total C and N measurements. Size-density (LUDOX) fractionations were performed on topsoil samples according to the procedure described by Meijboom *et al.* (1995).

Results were analyzed with AN(C)OVA (analysis of (co)variance) by using GENSTAT 5 (Payne *et al.*, 1987). To measure sustainability of different cropping systems, Van der Heide *et al.* (1992) introduced an index of production (I_P) to combine the yield of a number (n) of crops as follows:

$$Ip = \sum_{i=1}^{n} \frac{Y_i}{T_i}$$

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

Crop yields

Statistically significant ($P<0.05$) differences occurred between cropping systems (CS) for all crop yields (Figures 1 and 2). Nitrogen application did not significantly increase crop yields with the exception of maize (Table 4). No significant interaction between cropping system and N effect was found, except in cowpea production (data not shown).

Cassava yields declined over time since clearing of the forest and continued to do so even after the Imperata fallow (Figure 1). Intercropping systems significantly ($P<0.05$) increased cassava fresh tuber weight by up to 48% compared to the monocropping system during the later stages of the experiment.

Hedgerow intercropping systems (CS 2) gave lower maize, rice, groundnut and cowpea yields (Figure 2) than could be obtained in a crop rotation with legume cover crops (CS 3). Maize grain yields in the 80–20 rice/maize mixture were about 0.4 Mg ha^{-1} in the rice – groundnut rotation in the first year and about half as much when intercropped with cassava or hedgerows. Rice yield was less than 1 Mg ha^{-1} in the first cropping season for all cropping systems. However, in the second and third year yields in the rice/legume rotation (CS 3) increased to approximately 2 and 3 Mg ha^{-1} respectively. Rice yields intercropped with cassava (CS 1) or with hedgerows (CS 2) were about 1 Mg ha^{-1} less in year 2 and 1.5 Mg ha^{-1} less in year 3 than those grown

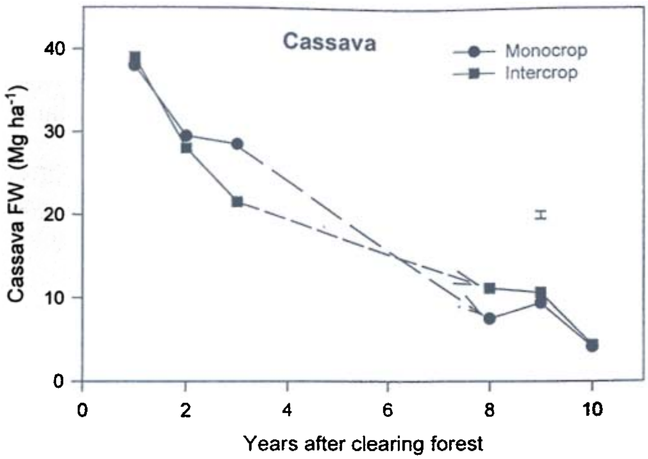


Figure 1. Cassava monocrop or intercropped (with rice-maize) yields since opening of the plot from logged-over forest in 1989.

in rotation with groundnut. Groundnut yields were modest and were reduced on average 45 % by hedgerow intercropping . Cowpea only yielded in 1995 and 1996 and yields in 1995 were very low. In year 2 there was a strong negative effect of the hedgerow cropping system on cowpea yield.

The index of productivity (I_P), based on marketed products, clearly differentiated the cropping systems (Table 5): for the cassava monoculture (CS 1A) and hedgerow

Table 4. Crops yields as affected by nitrogen supply (60 kg N ha^{-1}) (average of three years). s.e.d. is standard error of difference.

N treatment (kg N ha^{-1})	Cassava (Mg FW ha^{-1})	Rice (Mg DW ha^{-1})	Maize (Mg DW ha^{-1})	Groundnut (Mg Pods ha^{-1})	Cowpea (Mg Pods ha^{-1})
0	9.61	1.58	0.25	0.56	0.32
60	8.58	1.50	0.38	0.56	0.32
s.e.d.	0.484	0.036	0.054	0.026	0.038
F-prob.	>0.05	>0.05	0.028	>0.05	>0.05

Table 5. Index of productivity (I_p) of different cropping systems (see Table 2) over 3 years observation.

Crops	CS1A	CS1B	CS2A	CS2B	CS3A	CS3B
Cassava	**0.28**	0.35	–	–	–	–
Maize	–	0.04	0.04	0.08	0.08	0.13
Rice	–	0.58	0.57	0.47	0.94	0.97
Groundnuts	–	–	0.23	0.26	0.42	0.38
Cowpea	–	–	0.05	0.09	–	0.41
I_P	0.28	0.97	0.89	0.90	.44	.89
Average	0.63		0.90		1.66	

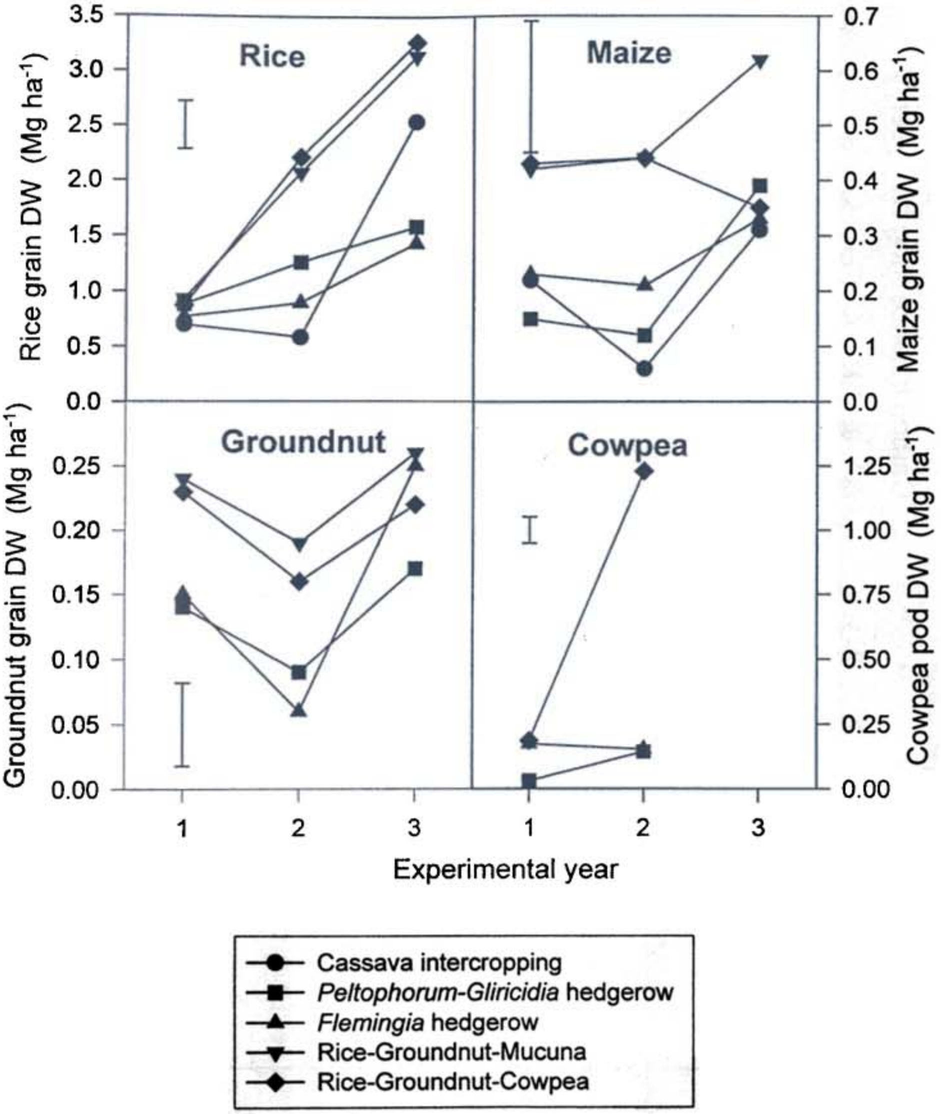
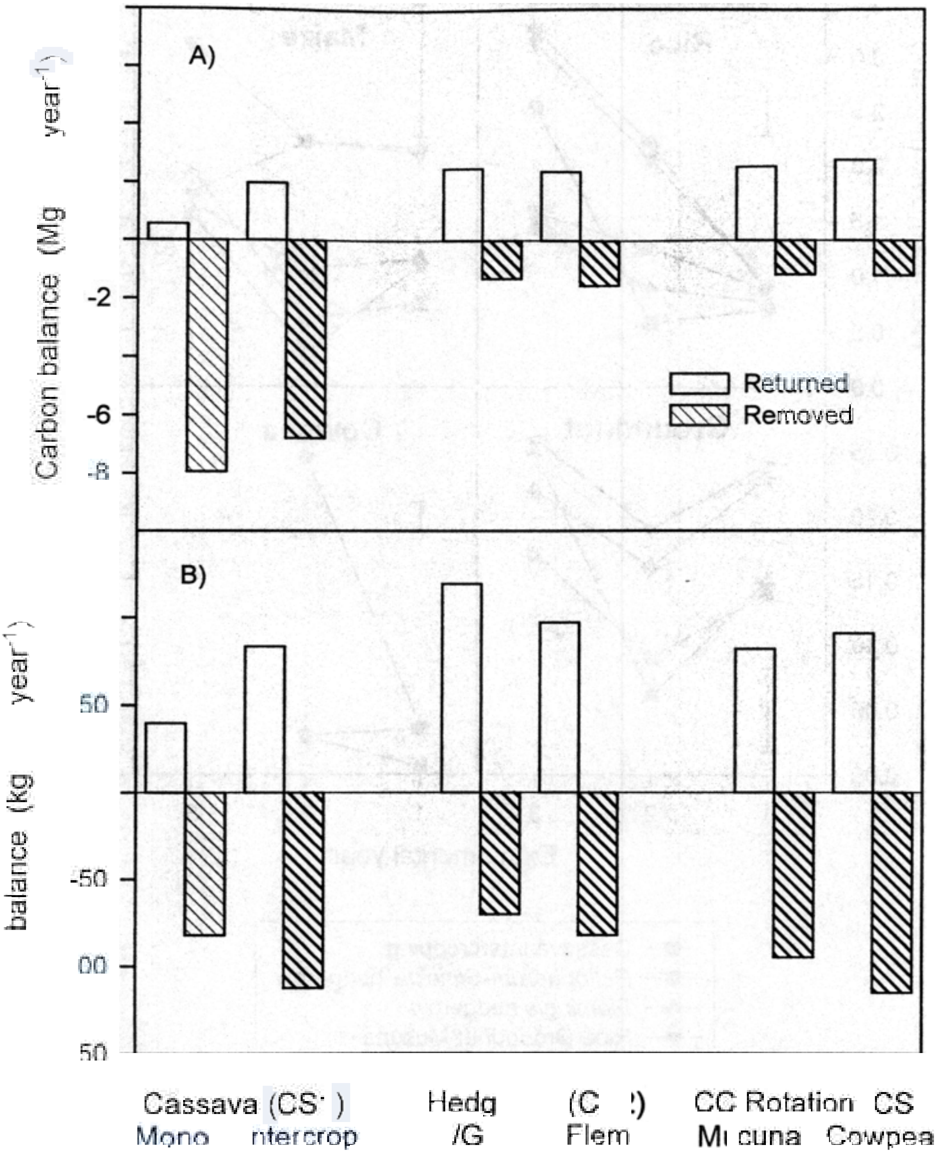


Figure 2. Crop yields for rice, maize, groundnut and cowpea yields as components of the various cropping systems.

intercropping systems (CS 2) 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 (CS 3) met the yield expectations as expressed in the I_p index, and maintained or increased productivity within the three cropping years. The cowpea grown in CS 3B



igure 3. C and N balances of different cropping systems (average of three years): Cassava monocrop (CS 1A) or intercrop (CS 1B); *Peltophorum/Glricidia* (CS :A) or *Flemingia* (CS 2B) hedgerows; cov crop rotations with *Mucuna* (CS 3A) or cowpea (CS 3

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Carbon and nitrogen balance

Figure 3a shows the amount of C removed from and returned to the soil in the various cropping systems. In the cassava-based systems (CS 1) much more C was removed from the plot (7 Mg ha^{-1} yr^{-1}) than in the other systems, while the amount returned to the soil was much smaller. Approximately 0.5–2 Mg C ha^{-1} yr^{-1} was returned to the plot as litter fall and green leaf of cassava (CS 1A+B), and maize plus rice residues (CS 1B) and about 5–8 Mg C ha^{-1} yr^{-1} was removed from the plot as tuber and stems. The hedgerow intercropping systems (CS 2) gave a positive C balance, as about 2.5 Mg C ha^{-1} yr^{-1} was returned to the plot as biomass pruning and crop residues and about 1.5 Mg C ha^{-1} yr^{-1} was removed out of the plot as yield. The cover crop rotations (CS 3) resulted in a surplus C of about 1.5 Mg ha^{-1} yr^{-1} where 2.6 Mg ha^{-1} yr^{-1} of C was returned to the plot as crop residues plus *Mucuna* (only in the 2nd year) and cowpea biomass, and about 1.1 Mg C ha^{-1} yr^{-1} was transported out of the plot.

The hedgerow intercropping systems (CS 2) resulted in a N surplus of about 15–50 kg ha^{-1} yr^{-1} returned to the soil whereas the positive N balance was only 10–20 kg ha^{-1} yr^{-1} for the cover crop rotation systems (CS 3) (Figure 3b). The cassava-based systems (CS 1) on the other hand had a negative N budget: about 60 kg ha^{-1} yr^{-1} was removed out of the plot. The addition of N via N_2-fixation of leguminous plants and via plant root turnover were excluded from these calculations.

Soil properties

The C_{org} content of the soil declined during the experiment from 2.55 (0–5) and 2.13 (5–15 cm depth) % in 1994 (Table 1), to an average of 2.20 and 1.75%, respectively, in 1995, and 2.07 and 1.84% in 1996 (Table 6). No significant effects were found of different cropping systems and N-applications on soil pH, total C over the 1995 – 1996 period (Table 6). However, the cropping systems differed in their impact on total N content of the soil with soil N in hedgerow systems among the highest and cassava monocrop with the greatest soil N loss (Table 1). The two sampling depths differed consistently in all soil parameters ($p<0.05$).

There were no statistically significant effects of treatments on size-density fractions of soil organic matter (LUDOX, data not shown). The average dry weight value for light, intermediate and heavy fractions were 2.6, 2.5 and 3.5 g kg^{-1} soil, respectively. The hedgerow intercropping, however, tended to increase dry weight of the light fraction (3.0 g kg^{-1} soil) compared to cassava-based cropping systems (2.6 g kg^{-1} soil) or cover crop rotation cropping systems (2.3 g kg^{-1} soil).

Discussion

Grain yield of upland rice increased with time, while cassava yields decreased particularly in the monocrop system. In the intercropped cassava the rice crop grew during the wettest part of the year, while cassava was still small and its roots shallow

Table 6. Soil properties of different cropping systems at 0–5 and 5–15 cm depth (NS= not significant different, F_{prob} > *0.05*; s.e.d. = standard error of difference). The effect of cropping systems in '96 was tested with the '95 data for the same plot as covariate.

Cropping system	Depth (cm)	pH-H_2O		pH-KCl		C_{org} (%)		N_{tot} (%)	
		'95	'96	'95	'96	'95	'96	'95	'96
Cassava	0–5	4.75	5.08	4.20	4.20	2.07	1.84	0.135	0.117
monoculture	5–15	5.22	5.20	4.27	4.00	1.82	1.67	0.113	0.100
Cassava	0–5	4.72	5.30	4.22	4.18	2.42	2.16	0.151	0.128
intercropping	5–5	5.10	5.20	4.23	4.02	1.67	1.91	0.121	0.120
Hedgerow	0–5	4.48	5.33	4.10	4.07	2.35	2.24	0.126	0.135
Peltoph/Glirici	5–15	5.00	5.00	4.23	3.90	1.87	2.00	0.119	0.125
Hedgerow	0–5	4.60	5.38	4.20	4.13	2.18	2.10	0.145	0.132
Flemingia	5–15	5.20	5.38	4.25	4.12	1.63	2.06	0.121	0.130
Rice-Gn-	0–5	4.65	5.25	4.18	4.18	2.15	2.16	0.140	0.133
Cowpea	5–15	5.20	5.33	4.32	4.12	1.97	1.71	0.123	0.113
Rice-Gn-	0–5	4.90	5.40	4.42	4.20	2.01	1.94	0.139	0.127
Mucuna	5–15	5.20	5.33	4.35	4.07	1.55	1.67	0.106	0.105
F-prob CropSys			NS		NS		NS		0.003
s.e.d			0.202		0.116		0.162		0.0044
Average CS	0–5	4.68	5.29	4.22	4.16	2.20	2.07	0.139	0.129
	5–15	5.18	5.26	4.28	4.04	1.75	1.84	0.117	0.116
F-prob Depth			<.001		0.013		0.036		<.001
s.e.d			0.042		0.021		0.453		0.0025

Thus rice may have captured nitrogen (Figure 3) that was probably lost by leaching from the monoculture. The rice residues left on the soil after harvest may not only have supplied N to the cassava but also protected the soil from erosion leading to higher soil C and N contents compared to the cassava monoculture (Table 6). The experiment thus provided partial support for hypothesis 1: *'Cropping systems with relatively deep-rooted components with a high N demand during the main leaching season can reduce N leaching and maintain long term soil productivity'*. However, even the intercropped cassava-based system was not likely to be sustainable, as it had a strongly negative C+N balance (Figure 3). The calculations of the C and N budgets may also help to explain the decline of cassava yield during the 3 years of cropping after slashing and burning the forest (Figure 1).

The experiment also provided support for hypothesis 2: *'Maintenance amounts of P fertilizer together with maximum use of crop residues can sustain crop productivity on acid soils in production systems with a large share of grain legumes and acid-soil tolerant crop varieties'*. All crops and crop varieties used in this experiment are (moderately) tolerant of the acid soil conditions of this Plinthic Kandiudult. In the first three years after slashing the *Imperata* fallow, the highest combined production index (I_p) was obtained under cereal-grain legume crop rotations systems (especially

CS 3B; Table 5). The most intensive cereal-grain legume crop rotation tested (CS 3B) was superior to the variant with *Mucuna* (CS 3A) partly because establishment of *Mucuna* was not possible in dry years. However, N off-take was higher than inputs from N_2 fixation of 34 and 18 kg N ha^{-1} yr^{-1} by groundnut and cowpea (Hairiah *et al.*, 2000) respectively, particularly in the third year with its higher yields, leading potentially to long term N shortages unless compensated by increased N_2 fixation by the crops.

Maize grain yields in the 80–20 rice/maize mixture were about 0.4 Mg ha^{-1} in the rice – groundnut rotation, where yield per individual plant were comparable with the 2 Mg ha^{-1} obtained as sole crop in hedgerow intercropping systems (Sitompul *et al.*, 1992), but stayed well below the yield potential of around 5 Mg ha^{-1} of the variety used. The low grain yield might be due to a low P-availability despite maintenance fertilization of P. However, the plant tissue analysis suggested adequate P supply at least for the hedgerow trees (Table 3). Competition by rice plants is thus likely to have reduced maize yields.

Hypothesis 3: '*Hedgerow intercropping can provide long term benefits in maintaining soil productivity at acceptable crop yield reduction due to competition*' however was not proven within the time-scale of this experiment. Rice yields in hedgerow intercropping were similar to those in the cassava intercropping system, but well below those in the cereal – grain legume rotations. The two hedgerow intercropping systems did not provide yield levels that are considered adequate ($I_p < 1$), although they provided a surplus C and N of about 2.5 C Mg ha^{-1} $year^{-1}$ and 15–50 kg N ha^{-1} yr^{-1}, respectively. The 3 year old hedgerow trees in CS 2A and 2B contributed 7–8 Mg ha^{-1} yr^{-1} of biomass in prunings returned to the soil. Apparently the positive effects via mulch and inputs from tree N_2 fixation of up to 35 kg N ha^{-1} yr^{-1} (Hairiah *et al.*, 2000) did not balance the negative impacts via shading given by trees (trees height >50 cm and the width of canopy about 50–75 cm) and competition for water and nutrients (Van Noordwijk, 1996c).

Hypothesis 4: '*In cassava-based production systems yields can not be maintained with a 'low external input' approach*' was proven. It appears that the rice + cassava intercrop combination can provide more complementarity in resource use over time than the hedgerow intercropping system, and is likely to be more attractive to farmers as the cassava tubers can be sold, while the hedgerow tree products can not. The system as tried is short of N, however, and the fertilizer rate tested that resembles what farmers think is affordable (60 kg ha^{-1}) is clearly not sufficient to balance N exports. The price of cassava tuber in most years does not justify the use of fertilizer at 'replacement' levels (Van Noordwijk *et al.*, 1997a), so soil mining is almost inevitable. The high biological nutrient use and scavenging ability of the crop allows this mining to continue to levels where other crops can not be easily established.

Overall this experiment provides further evidence for the trade-off between short term profitability and longer term sustainability of food crop production systems under the conditions in Northern Lampung. The intensive grain legume – cereal rotations (CS 3) at moderate fertilizer input levels appear to provide the best compromise.

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