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Soil property changes in contour hedgerow systems on sloping land in the Philippines

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Abstract. The impact of contour hedgerow systems on soil sustainability under acidic conditions has been widely criticized. A study was undertaken to determine the effects of management and hedgerow species on soil properties. *Cassia spectabilis* (a non-N-fixing tree legume), *Gliricidia sepium* (an N-fixing tree legume), *Pennisetum purpureum* (a forage grass), and *Stylosanthes guyanensis* (a forage legume) contour barriers were compared with an open field (non-hedgerow treatment) over one cowpea and two rice seasons. Three types of management viz.: prunings applied + $N_0P_0K_0$, prunings applied + $N_{50}P_{20}K_{20}$ and prunings removed + $N_{50}P_{20}K_{20}$ were used as subplot treatments. The soils were strongly acidic (pH 4.5) and classified as clay Orthoxic Palehumult. *Cassia* performed better than the other species in terms of pruning biomass, N and P contributions over a period of 20 months. There was a combined positive effect of pruning biomass and fertilizers on rice and cowpea yields in *Pennisetum* and *Gliricidia* systems, while a tendency towards a positive effect of pruning biomass on rice was found in the *Cassia* system. The pruning biomass and/or fertilizer application did not significantly influence the top soil organic C, N and available P in the hedgerow systems. Soil bulk density was significantly reduced by the application of *Cassia* prunings after 12 months. Organic C, N and P dynamics indicated that in situ pruning biomass was not sufficient to maintain their level in the soil. But the *cassia* systems with prunings applied + $N_{50}P_{20}K_{20}$ experienced the lowest degradation in soil organic C (2.1 t ha^{-1}) followed by the *Gliricidia* systems (4.1 t ha^{-1}). The overall results imply that the application of pruning and inorganic fertilizer is imperative to conserve soil resources, and non-N-fixing tree species can exert a significant advantage in biomass and thereby in soil N-recycling under acidic soil.

Introduction

Constant destruction of primary forest cover and continuous cropping have significantly impaired the hydrologic equilibria and triggered massive top soil erosion. This has led to decline in soil fertility and thereby crop yield. One of the possible technologies to address this problem is the contour hedgerow system or alley cropping (Kang et al., 1981; Nair, 1984).

Until recently, it has usually been postulated that the contour hedgerow system allows an efficient mechanism to recycle nutrients, maintain soil organic matter and protect the soil from surface erosion (Kang et al., 1990).

Nevertheless, the data supporting the contentions of nutrient recycling and maintenance of organic matter are scarce (Sanchez, 1987). In a review of hedgerow intercropping systems, Kang et al. (1990) found that this system is mostly successful in Alfisols and Andosols which are dominated by base-rich, naturally fertile soils. Experimental evidence, so far, indicates that the sustainability attribute to this system is limited in acid and low fertility soils because of insufficient nutrient recycling from the pruning biomass (Fujisaka and Garrity, 1989; Szott et al., 1991). These soils dominate most of the uplands in the humid and subhumid tropics (Fujisaka and Garrity, 1989). These authors have suggested studying alternative nutrient management techniques and selecting suitable hedgerow species for acidic soil conditions. Investigation of sustainability attributes of such alternative management practices and hedgerow species would be of immense value to the agronomist/agro-ecologist. It would enable them to manipulate the system components in order to make the entire system effective for a specific site.

Multipurpose, fast growing tree legumes are important components of contour hedgerow systems. *Cassia spectabilis* DC (*Senna spectabilis* DC. Irwin and Barnaby) and *Gliricidia sepium (Jacq.) steud* have been widely used in south-east Asia for their fast growth characteristics and multipurpose nature (Garrity and Mercado, 1994). *Cassia spectabilis* shows excellent adaptation to strongly acidic and infertile soils (Maclean et al., 1992) but no fodder value. It is a non-nodulating legume and does not fix atmospheric N (Ladha et al., 1993), but does still supply large amounts of N through prunings (Maclean et al., 1992). *Gliricidia sepium* is a nodulated legume in which 30–55% of the plant’s N uptake may come from atmospheric N fixation (Ladha et al., 1993).

Pennisetum purpureum and *Stylosanthes guyanensis* are also popular hedgerow alternatives among farmers of the Philippines, because of their faster natural terrace formation for soil erosion control (Fujisaka and Garrity, 1991). *Pennisetum purpureum* is also extensively used for ruminant fodder because of its excellent rate of biomass accumulation and wider adaptation (Garrity and Mercado, 1994).

The maintenance of soil fertility is one of the crucial issues in evaluating the sustainability attribute of any land use system. As the amount of pruning biomass produced in acid soils is too low to conserve soil resources, it is, therefore, hypothesized that application of hedgerow prunings and inorganic fertilizers will maintain soil fertility over time. To test this hypothesis, this study determined the effects of management and hedgerow species on soil properties, and also investigated the suitable hedgerow species in a contour hedgerow system in acid soils.

Materials and methods

Site description

The experiment was conducted at the International Rice Research Institute (IRRI) out-reach station, Cavinti (14°17′ N latitude and 121°30′ E longitude with a mean elevation of 301 m above sea level) at Laguna, Philippines from June 1991 to January 1993. The mean annual rainfall is 2522 mm with maximum rainfall occurring from July to December and a short dry season lasting from February to April.

The experimental site had a slope of 8–30%, with slight to moderate soil erosion. The soil is well drained and classified as clay Orthoxic Palehumult. It is characterized by low pH (4.5 in water), low base saturation (0.214, 1.03, 0.354 m eq/100 g K, Ca, Mg, respectively), very low available phosphorus (4.40 ppm in Bray II), and high exchangeable acidity (mainly caused by Al).

Experimental design, lay-out and management

The experiment utilized three-year-old existing hedgerows with three replicates in a split plot design with subplots in a Latin square. The mainplot treatments (Factor A) consisted of an open field and four hedgerow species as follows:

OF – open field (without contour bund, no hedgerow)
GS – contour bund with *Gliricidia sepium* established from seedlings
CS – contour bund with *Cassia spectabilis* established from seedlings
PP – contour bund with *Pennisetum purpureum* established from cuttings
SG – contour bund with *Stylosanthes guyanensis* established from seed.

The subplot treatments (Factor B) consisted of three management practices which were imposed on the alley as follows:

M1 – Prunings applied as mulch + no fertilizer
M2 – Prunings applied as mulch + $N_{50}P_{20}K_{20}$
M3 – Prunings removed + $N_{50}P_{20}K_{20}$

The above treatments were laid out in the following way to form a split plot design with subtreatments in a Latin square.

Replication – I

CS	PP	GS	SG	OF
M2	M2	M3	M1	NPK
M1	M3	M2	M3	O
M3	M1	M1	M2	NPK

Replication – II

PP	CS	OF	SG	GS
M2	M2	O	M1	M3
M1	M3	NPK	M3	M1
M3	M1	NPK	M2	M2

Replication – III

OF	GS	PP	SG	CS
NPK	M2	M3	M3	M1
NPK	M3	M2	M1	M2
O	M1	M1	M2	M3

The open field treatment received no pruning biomass but inorganic fertilizer. To reduce the experimental error, the subtreatments of the same hedgerow species in three replications were arranged down the slope forming a Latin square. The whole experiment covered a total area of approximately 2000 m^2 including the borders and alleyways between the main plots. The unit size of the alley comprised 6 × 6 m, while that of the contour bund was 6 × 2 m. Each contour bund comprised two rows of hedgerow species. The seedlings of *Cassia* and *Gliricidia* were transplanted in rows at 50 cm intervals, with 25 cm between plants. The cuttings of *Pennisetum* and seeds of *Stylosanthes* were also planted in rows 50 cm apart, with plants at 10 cm intervals.

All alleys, including the control plots, were prepared by plowing across the slope for the rice-cowpea cropping pattern. Upland rice (cv UPLRI-5) was planted during the period 5–7 July, 1991, and cowpea (cv EG-3) from 20 to 22 November, 1991. A third rice crop was also planted between 3 and 5 July, 1992. Rice was seeded at the rate of 100 kg ha^{-1} in 30 cm furrows, while cowpea was planted at 50 × 25 cm spacing with 3–4 seeds/hill.

The leguminous tree hedgerows, viz. *Gliricidia sepium* and *Cassia spectabilis* were pruned down to 50 cm. The grass *Pennisetum purpureum* and the forage legume *Stylosanthes guyanensis* were cut down to 30 cm. These operations were carried out every seven to eight weeks depending on their growth, with the exception of the first pruning. The first pruning was done several months after the last pruning had been done (i.e. before the study commenced). Hedgerow prunings were applied uniformly to the alley as mulch. All subplots received rice straw/cowpea residues as mulch. The removal of prunings was considered as a treatment to simulate the situation when ruminant fodder is to be supplied from the system. Moreover, this treatment was designed to provide comparative information on the degree of competitiveness of the hedgerows with the associated field crops.

For fertilization, N P K fertilizer was applied to rice at the rate of

50 kg N ha^{-1}, 20 kg P ha^{-1} and 20 kg K ha^{-1} from Urea, Triple Superphate and muriate of potash, respectively. All P and K were applied before planting as basal. Half of the N was top dressed at 28 days after emergence (DAE) and the rest at seven days before panicle initiation (DBPI). No inorganic fertilizers were applied to cowpea.

Rice and cowpea were harvested manually when the crop reached physiological maturity during 14–16 November 1991 and from 7 March, respectively. After harvesting, rice panicles and cowpea pods were shelled to obtain the grains.

Biomass collection and rate of decomposition

Fresh weights of leaves and green stems (branches, twigs, etc.) of hedgerow species were taken separately after pruning from each contour bund. Prunings of one contour bund was considered as a management tool either applied to adjacent alley (i.e. subplot) or removed from the field. Similarly, fresh weight of alley crop residues (rice straw and cowpea residues) at harvest were recorded from each subplot. One kilogram of fresh herbage and crop residues were oven-dried separately at 70 °C for 48 h to obtain per cent dry matter in the fresh biomass.

A composite root sample was made by collecting soils from a depth of 0.4 m from different rows of rice and cowpea using specially designed metal cores (Craswell and Castillo, 1979). Then the crop roots were separated from soil and others by washing repeatedly over a 1 mm screen with a tap-water jet. After complete washing, the fresh weight of the samples was taken and then they were oven-dried at 70 °C to obtain the dry matter yield, as stated in the above ground biomass.

The rate of dry matter decomposition of the herbage, crop residues and crop roots was monitored for the whole period of crop cycle. For this purpose, 50 g (fresh) each of green stems and leaves of pruned hedgerows and crop residues were separately placed on the soil surface after placing them in plastic nets (30 × 20 cm) of mesh size 1 mm. For *Stylosanthes*, stems and leaves were not separated. This process of litter bag placement was repeated for every pruning operation. During the crop's maturity stage, litter bags of each pruning operation were collected, washed and oven-dried to obtain the dry matter yield of decomposed litters. The per cent dry matter loss for a particular period of time was calculated as follows:

$$\text{Decomposition rate} = \frac{\begin{array}{c}\text{Amount of original dry matter placed} - \\ \text{amount of dry matter remaining over time}\end{array}}{\text{Amount of original dry matter placed}} \times 100$$

Plant tissue analysis

The oven-dried herbage, crop residues, decomposed biomass, crop roots and grains were ground and analyzed for nitrogen and phosphorus. Prunings were analyzed for nutrient content.

Nutrient content of the dry matter was calculated as:

$$\text{Kg nutrient} = \frac{\text{Total dry matter yield} \times \text{\% nutrient}}{100}$$

The amount of nutrient released upon decomposition was calculated as:

$$\text{\% Nutrient release} = \frac{\begin{array}{c}\text{Amount of nutrient present in the dry matter placed} - \\ \text{amount nutrient present in the dry matter remaining}\end{array}}{\text{Amount nutrient present in the dry matter placed}} \times 100$$

$$\text{Amount nutrient release} = \frac{\begin{array}{c}\text{\% Nutrient release} \times \\ \text{Amount nutrient present in the total dry matter}\end{array}}{100}$$

Soil analysis

Bulk density was measured before the experiment and after the rice-cowpea cycle. Undisturbed soil samples were collected from four locations down the slope from 0–15 cm of each subplot by the core method as described by Blake and Hartge (1986).

Before the experiment, a composite sample was made for each of the main plots by collecting soils from four locations down the slope of all replications. Immediately after the harvest of cowpea in 1992, a second sampling was done making a composite for each of the subplots. Finally, after the harvest of rice in the 1992 wet season, a representative soil sample was collected from all replications for each of the subplots. In each case, soil samples were taken from 0–15 cm depth with a metallic core. The collected soil samples were then air-dried, pulverized, sieved and used for analysis as follows:

a) pH: by glass electrode pH meter with 1:1 soil to water ratio as outlined by Jackson (1962).
b) Organic carbon: by the Walkley–Black oxidation method described by Black et al. (1965).
c) Total nitrogen: by micro-Kjeldahl digestion and calorimetric estimation as indophenol blue using an auto-analyzer system (Varley, 1966).
d) Available phosphorus (P): by the Bray II method (Bray and Kurtz, 1945).

Crop yield

Grain yield of rice and cowpea was recorded based on the full alley basis (area occupied by the crop only). Grain yield was computed at 14% moisture content.

Statistical analysis

Analysis of variance (ANOVA) for split plot design with subplot treatments in a Latin square was done using IRRISTAT (1992) and the Statistical Analysis System (SAS, 1988). Because of special arrangement of subplots in a Latin square, row variability within the main plot was computed in SAS and then deducted from the experimental error of the ANOVO done in IRRISTAT. *Cassia spectabilis* could not be analyzed statistically because of its minimum population stand which died in one replication. For this minimum population, the system in that replication did not seem to have hedge-crop interaction. The data, however, were presented as mean of two replications which served only as a reference point. The format of analysis of variance (ANOVA) is presented in Table 1.

Results

Hedgerow pruning biomass productivity and crop yield

The highest pruning dry matter among the hedgerows was received from *Cassia spectabilis* (Table 2) during all crop cycles (from 1.4–5.8 t ha^{-1}/crop cycle). *Gliricidia sepium* and *S. guyanensis* have the lowest prunings per crop cycle (0.4–1.4 t ha^{-1} and 0.7–1.3 t ha^{-1}, respectively). The dry matter of *Cassia spectabilis* was significantly reduced over crop cycles (from 5.6–5.8 to 2.0–2.5 to 1.4–1.6 t ha^{-1} in rice–cowpea–rice, respectively). The yield of *G. sepium* and *P. purpureum* dropped significantly after the rice crop in 1991, but thereafter remained stable in the cowpea and rice crops of 1992. Pruning yields of *Stylosanthes guyanensis* did not change significantly over crop cycles. No significant variation was found among the management subplots within species. The exception was the significantly higher dry matter of *P. purpureum* species (5.6 t ha^{-1}) in prunings removed + $N_{50}P_{20}K_{20}$ subplot treatment compared to that in prunings applied + $N_0P_0K_0$ treatment (4.7 t ha^{-1}) during the 1991 rice cycle. It was noted that the management practices for hedgerows in all the subplots were the same. They differed only in the alley crops grown between the hedgerows. In spite of similar management practices, this difference in biomass production of *Pennisetum* may be attributed to variation in hedgerow stand density.

Cassia spectabilis released a higher amount of N (33–155 kg ha^{-1}) biomass over crop cycles than the other hedgerow species, which were comparable

Table 1. Format of analysis of variance.

Source of variation	Degree of freedom
Replication	$r - 1 = 2$
Main plot factor (A)	$a - 1 = 3$
Hedgerow vs. no. hedgerow (A1)	$m - 1 = 1$
Among hedgerow species (A2)	$h - 1 = 1$
Tree vs. grass (A2.1)	$l - 1 = 1$
Among grasses (A2.2)	$g - 1 = 1$
Error (a)	$(r - 1)(a - 1) = 6$
Subplot factor	
Rows	$ka(b - 1) = 8$
Management practices (B)	$(b - 1) = 2$
A × B	$(a - 1)(b - 1) = 6$
A1 × B	$(m - 1)(b - 1) = 2$
A2 × B	$(h - 1)(b - 1) = 4$
A2.1 × B	$(l - 1)(b - 1) = 2$
A2.2 × B	$(g - 1)(b - 1) = 2$
Error (b)	$a(b - 1)(r - 1 - k) = 8$
Total	$rab - 1 = 35$

Notation: a = number of main treatments; b = number of sub-treatments; m = number of groups of main treatments, e.g. trees and grasses; h = number of hedgerow species; l = number of groups in hedgerows, e.g.: trees and grasses; g = number of grass hedgerow species; r = number of replication = kb; k = any multiple of sub-unit treatment = 1, i.e. $r = 1 \times 3 = 3$.
Adapted from Cochran and Cox (1957).

among themselves (Table 2). The exception was the *P. purpurem* pruning which released significantly higher N (53–57 kg ha^{-1}) compared to *G. sepium* (32–36 kg ha^{-1}) and *S. guyanensis* (21–23 kg ha^{-1}) during the 1991 rice. The average N contribution in the prunings of *Cassia* over all 3 crop cycles and management was 298% higher than that of *Gliricidia*. This indicates that non-N-fixing tree exerted an advantage over N-fixing tree legume in acidic soil because of its higher biomass production.

Like N-release, *Cassia spectabilis* prunings released a significantly higher amount of P during rice (8.6–8.9 kg ha^{-1}) and cowpea (3.6–4.4 kg ha^{-1}) 1991 cycle than the other species (Table 2). *G. sepium* and *S. guyanensis* prunings released the lowest amount of P during the same cycle (0.8–2.8 kg ha^{-1} and 1.7–2.5 kg ha^{-1}, respectively). The N and P release from hedgerow prunings over the three crop cycles resembled the same trend of reduction as the dry matter yield.

No significant variation was observed in N and P release among the management treatments. The exception was found in *Pennisetum purpureum* during 1991 rice where significantly the lowest amount of P was released from the prunings applied + $N_0P_0K_0$ treatment due to its lower dry matter compared to the other treatments (Table 2).

Table 2. Dry matter and nutrient release via pruning biomass to the soil as affected by crop cycle, management and hedgerow species at Cavinti, Laguna, the Philippines.

Crop cycle and species	Dry matter (t ha^{-1})			N-release (kg ha^{-1})			P-release		
	M1	M2	M3	M1	M2	M3	M1	M2	M3
Rice cycle (1991 Wet season)									
CS	5.8	5.7	5.6	155	153	152	8.9	8.7	8.6
SG	1.4	1.4	1.3	35	36	32	2.7	2.8	2.4
PP	4.7	5.3	5.6	49	53	57	6.4	7.1	7.9
SG	1.0	1.0	0.9	23	22	21	1.9	1.8	1.7
Cowpea cycle (1991 Dry season)									
CS	2.0	2.5	2.1	45	54	50	3.6	4.4	4.0
GS	0.5	0.4	0.4	10	8	9	1.0	0.8	0.8
PP	1.5	1.9	1.8	9	11	11	2.1	2.7	2.6
SG	1.0	1.2	1.3	17	20	22	1.9	2.3	2.5
Rice cycle (1992 Wet season)									
CS	1.4	1.6	1.6	33	38	40	2.0	2.3	2.4
GS	0.7	0.6	0.7	19	15	17	1.4	1.1	1.3
PP	1.3	1.6	1.5	14	16	16	1.8	2.1	2.2
SG	0.7	1.1	1.3	16	25	28	1.3	2.0	2.3

Comparison	Dry matter LSD (5%)	N-release LSD (5%)	P-release LSD (5%)
2-Species means at each Managmenet × Cycle	0.81	15.1	1.3
2-Management means at each Species × Cycle	0.81	15.4	1.3
2-Cycle means at each Species × Management	0.59	9.8	1.0

CS = *Cassia spectabilis*; GS = *Gliricidia sepium*; PP = *Pennisetum purpureum*; SG = *Stylosanthes guyanensis*.
M1 = prunings applied + $N_0P_0K_0$; M2 = prunings applied + $N_{50}P_{20}K_{20}$; M3 = prunings removed + $N_{50}P_{20}K_{20}$.

Crop yield

Rice and cowpea yields are presented in Table 3. During 1991 rice, the grain yield with $N_0P_0K_0$ plus prunings of *Stylosanthes guyanensis* (0.695 t ha^{-1}) and open field treatment (0.83 t ha^{-1}) were significantly lower than that with prunings applied + $N_{50}P_{20}K_{20}$ treatment (1.079 t ha^{-1} in *Stylosanthes* and

Table 3. Grain yield of upland rice and cowpea on full alley basis as affected by alternative management practices and hedgerow species in a contour hedgerow system on sloping acidic land at Cavinti, Laguna, Philippines.

Species	Management		
	M1	M2	M3
1991 Wet season		Upland rice yield (t ha^{-1})	
OF	0.830	1.130	0.876
GS	0.894	1.048	0.805
PP	0.682	0.706	0.632
SG	0.695	1.079	1.090
CS[a]	0.971	0.994	0.882
1992 Wet season			
OF	1.869	2.127	2.222
GS	2.049	2.120	1.790
PP	1.839	1.916	1.576
SG	1.955	1.962	1.753
CS[a]	2.176	2.104	1.732
1991 Dry season		Cowpea yield (t ha^{-1})	
OF	0.440	0.587	0.650
GS	0.438	0.579	0.563
PP	0.374	0.517	0.288
SG	0.456	0.469	0.569
CS[a]	0.578	0.670	0.372

Comparison	SED	LSD (5%)
		Upland rice
2-Species means at each management × year	0.137	0.307
2-Management means at each species × year	0.121	0.262
2-Year means at each species × management	0.110	0.217
		Cowpea
2-Species means at each management	0.100	0.238
2-Management means at each species	0.087	0.200

[a] Means of two replications, not statistically analyzed.

OF = Open field system; GS = *Gliricidia sepium*; PP = *Pennisetum purpureum*; SG = *Stylosanthes guyanensis*; CS = *Cassia spectabilis*.

M1 = pruning applied + $N_0P_0K_0$; M2 = pruning applied + $N_{50}P_{20}K_{20}$; M3 = pruning removed + $N_{50}P_{20}K_{20}$.

1.13 t ha^{-1} in open field). The result indicates the presence of a positive fertilizer effect in *Stylosanthes* and open field treatments. This effect of fertilizer was still observed during 1992 rice. The yield with prunings of *Stylo*, either retained or removed but plus $N_{50}P_{20}K_{20}$, were comparable, indicating no pruning biomas effect. The *Stylosanthes* hedgerows contributed negligible pruning biomass, so in that sense was similar to the open field.

No significant difference in grain yield was found in *G. sepium* and *P. purpureum* systems in the absence or presence of prunings and or fertilizer during 1991 rice indicating no effect of prunings and fertilizers. During 1992, the yield was significantly higher with prunings alone and prunings + fertilizer ($N_{50}P_{20}K_{20}$) than that with fertilizer alone in the *G. sepium* and *P. purpureum* systems. These results indicate a strong positive effect of continuous application of pruning biomass on grain yields. In *C. spectabilis*, rice yields with prunings applied + $N_{50}P_{20}K_{20}$ during 1991 (0.994 t ha^{-1}) and 1992 (2.104 t ha^{-1}) were respectively 13% and 22% higher than those with prunings removed + $N_{50}P_{20}K_{20}$ (0.882 t ha^{-1} in 1991 and 1.732 t ha^{-1} in 1992) indicating a tendency for a positive effect of pruning biomass application.

Significantly higher yield of cowpea was observed with $N_{50}P_{20}K_{20}$ (0.650 t ha^{-1}) compared to $N_0P_0K_0$ (0.440 t ha^{-1}) in the open field treatment indicating a positive effect of fertilizer. In *G. sepium* and *S. guyanensis*, cowpea yield with pruning applied + $N_0P_0K_0$ was comparable to that with prunings applied + $N_0P_0K_0$ and prunings removed + $N_{50}P_{20}K_{20}$ indicating no positive effect of prunings and fertilizer. But *P. purpureum* treatment had significantly higher cowpea yield with prunings applied + $N_{50}P_{20}K_{20}$ (0.517 t ha^{-1}) than that with prunings removed + $N_{50}P_{20}K_{20}$ (0.288 t ha^{-1}). This result indicates a positive effect of pruning biomass on cowpea grain yield. Similar pruning biomass effect was found in *C. spectabilis* where yield with prunings applied + $N_{50}P_{20}K_{20}$ (0.67 t ha^{-1}) was 80% higher than that with prunings removed + $N_{50}P_{20}K_{20}$ (0.372 t ha^{-1}).

Grain yields were significantly lower in *P. purpureum* (0.63–1.58 t ha^{-1} rice and 0.29 t ha^{-1} cowpea) than that in the open field treatment (0.88–2.22 t ha^{-1} rice and 0.65 t ha^{-1} cowpea) with fertilizer alone. This indicates the existence of competition between the hedge and the crops. This competition was, however, compensated by the application of pruning biomass during rice 1992 and cowpea as there was no significant variation in grain yield between *P. purpureum* and open field systems. A similar trend was observed in *G. sepium* and *S. guyanensis* during 1992 rice. There was a 19.5% reduction in rice grain yield during 1992 and 45.9% reduction in cowpea yield in *C. spectabilis* compared to the fertilizer treatment in the open field. This reduction was also compensated apparently by the application of pruning biomass. No significant variation in grain yield was observed among the hedgerow species where only prunings were applied. Rice yield was found to be significantly lower in the 1991 wet season compared to that of 1992. Severe drought spell during 1–10, 1991 affected the milking and starch formation stage of rice, thereby causing lower grain yield (Figure 1). In addition, solar

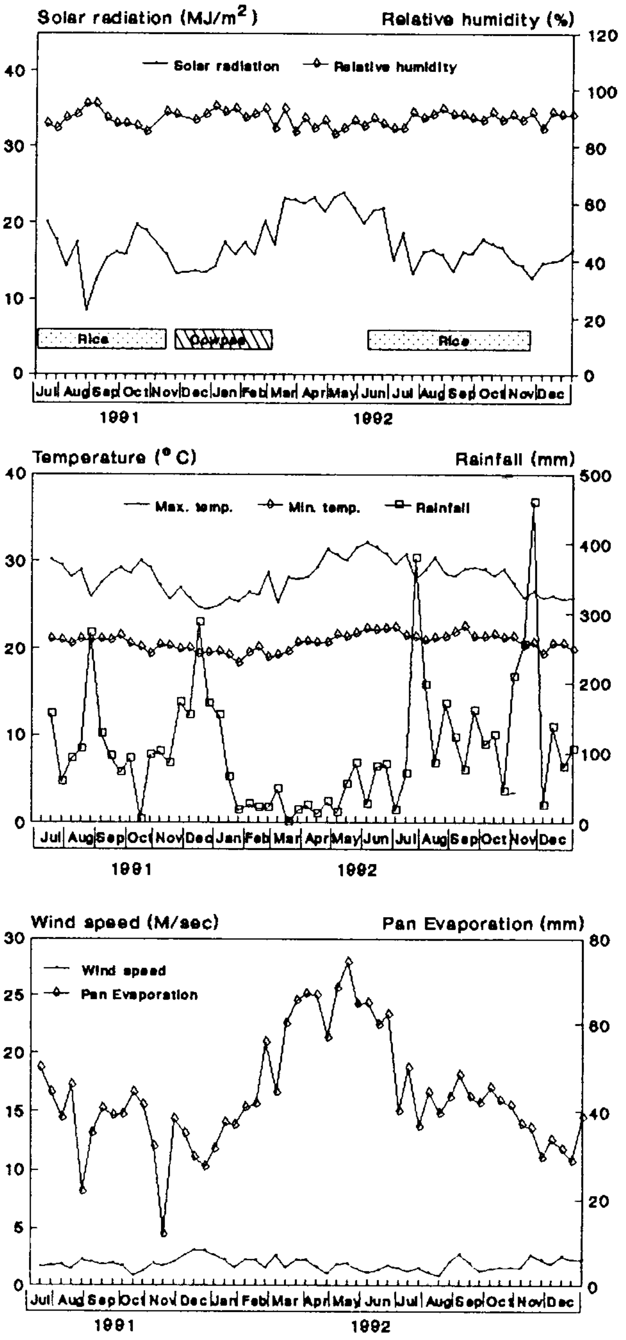

Figure 1. Meteorological data per 10-day period at Cavinte, Laguna, Philippines from July, 1991 through December, 1992.

radiation sharply declined (below 10 MJ/m^2) during 11–20 August 1991. This might have affected LAI, thereby causing lower dry matter production of 1991 rice compared to that in 1992.

Soil property changes

The results after 20 months (Table 4) showed that the top soil (0–15 cm) organic carbon, total nitrogen, available phosphorus and pH were not significantly affected by management and hedgerow species except *Cassia spectabilis*. It is noted that the *Cassia spectabilis* system could not be analysed statistically after 20 months due to its minimum population and hence an assessment of this system was made based on the results of two replications.

Organic C and N concentration declined over time in all the hedgerow treatments (Table 4a and 4b). The exception was an enrichment in organic carbon with $N_{50}P_{20}K_{20}$ in the open field system. The average organic C of two identical $N_{50}P_{20}K_{20}$ in the open field was higher over 20 months (2.47%) than the initial level (2.41%). This peculiar result could be attributed to compositing of initial soil samples by main plots. This composite analysis may have caused a lower initial value of O.C in subplot of open field systems than the actual value. Also, one of the $N_{50}P_{20}K_{20}$ treatments in the open field system reduced organic carbon over time. The extent of reduction of O.C and N was, however, less with prunings applied + $N_{50}P_{20}K_{20}$ compared to prunings applied + $N_0P_0K_0$ and prunings removed + $N_{50}P_{20}K_{20}$ in all the hedgerow treatments in general.

The combination of pruning biomass and inorganic fertilizers minimized the reduction of soil O.C and N over time. In *Cassia spectabilis*, the reduction of soil O. C after 12 months was lower in treatments with prunings alone (0.05%) and prunings + fertilizer (0.05%) than in treatments where only fertilizers was applied (0.13%).

At 12 months, higher values of soil O.C and N (Table 4a and 4b) were observed with all managements of *Cassia spectabilis* (2.44–2.52% O.C, 0.233–0.244% N) compared to other hedgerow species (2.22–2.42% O.C, 0.201–0.225% N). No significant differences were found in soil O.C and N among the treatments of *Gliricidia*, *Pennisetum*, *Stylosanthes* and open field regardless of management after 20 months.

Numerically, higher values of available P (7.6–10.5 mg ha^{-1}) were obtained over 20 months (Table 4c) with prunings + fertilizers compared to other managements (4.7–7.6 mg ha^{-1}), even higher than the initial values (5.7–6.8 mg ha^{-1}). The improvement of P level also occurred when only fertilizers were applied, except in *Pennisetum purpureum*. This result indicates that there was an observed fertilizer effect on the soil P availability. Among the hedgerow species, *Cassia spectabilis* with prunings + fertilizer treatment increased the initial level of available P (6.2 mg ha^{-1}) over 20 months (18.0 mg ha^{-1}). This improvement may be attributed to the continuous application of large amounts of prunings to the soil compared to other hedgrow species (Table 2).

A sharp decline of available P occurred over 12 months and an increase

Table 4. Soil chemical property changes (0–15 cm, topsoil) as affected by alternative management practices and hedgerow species in a contour hedgerow system on sloping acidic land at Cavinte, Laguna, Philippines.

(a) Per cent Organic Carbon

Species	Management practices						
	Initial	After 12 months[a]			After 20 months		
		M1	M2	M3	M1	M2	M3
OF	2.41	2.50	2.68	2.26	2.24	2.63	2.31
GS	2.68	2.22	2.34	2.32	2.13	2.43	2.25
PP	2.80	2.32	2.34	2.32	1.92	2.33	2.13
SG	2.73	2.38	2.22	2.42	2.26	2.28	2.37
CS$_a$	2.57	2.52	2.52	2.44	–	2.54	–

	After 20 months	
Comparison	SED	LSD (5%)
2-Species means at each Management	0.16	0.38
2-Management means at each Species	0.17	0.40

(b) Per cent Nitrogen

Species	Management practices						
	Initial	After 12 months[a]			After 20 months		
		M1	M2	M3	M1	M2	M3
OF	0.265	0.230	0.225	0.204	0.210	0.243	0.223
GS	0.287	0.216	0.224	0.219	0.214	0.237	0.212
PP	0.303	0.218	0.225	0.214	0.186	0.224	0.198
SG	0.278	0.214	0.201	0.225	0.218	0.220	0.221
CS$_a$	0.286	0.244	0.236	0.223	–	0.235	–

	After 20 months	
Comparison	SED	LSD (5%)
2-Species means at each Management	0.017	0.039
2-Management means at each Species	0.016	0.037

thereafter (Table 4c) particularly with prunings applied + $N_{50}P_{20}K_{20}$ and prunings removed + $N_{50}P_{20}K_{20}$ All these levels of phosphorus availability after 20 months are still below the critical level (12 mg kg^{-1}), especially for growth of common crops. Soil pH showed a declining trend over 12 months and an increase thereafter (Table 4d) regardless of management and hedgerow species, including the open field system. In general, pH values with prunings applied + $N_{50}P_{20}K_{20}$ were lower compared to other managements after 12 and 20

Table 4. (Continued).

(c) Available Phosphorus (mg/kg)

Species	Management practices						
	Initial	After 12 months[a]			After 20 months		
		M1	M2	M3	M1	M2	M3
OF	6.6	2.6	5.5	2.6	4.70	7.80	7.67
GS	6.1	3.0	3.2	4.0	4.83	10.57	6.90
PP	6.8	3.7	3.7	3.3	5.37	7.63	4.70
SG	5.7	3.4	2.7	3.0	6.30	7.93	6.20
CS$_a$	6.2	2.8	3.4	2.9	–	18.00	–

	After 20 months	
Comparison	SED	LSD (5%)
2-Species means at each Management	2.73	6.46
2-Management means at each Species	2.52	5.80

(d) pH

Species	Management practices						
	Initial	After 12 months[a]			After 20 months		
		M1	M2	M3	M1	M2	M3
OF	4.3	3.89	3.83	3.87	4.29	4.26	4.25
GS	4.6	3.89	3.82	3.91	4.30	4.25	4.26
PP	4.5	3.96	3.86	3.87	4.49	4.33	4.35
SG	4.5	3.81	3.78	3.93	4.31	4.29	4.33
CS$_a$	4.5	3.91	3.84	3.92	–	4.03	–

			After 20 months	
Comparison			SED	LSD (5%)
2-Species means at each Management	0.12	0.29		
2-Management means at each Species	0.07	0.16		

[a] Composite of two replications, not statistically analyzed.

OF = Open field system, GS = *Gliricidia sepium*, PP = *Pennisetum purpureum*, SG = *Stylosanthes guyanensis*, CS = *Cassia spectabilis*.

M1 = pruing applied + $N_0P_0K_0$; M2 = pruning applied + $N_{50}P_{20}K_{20}$; M3 = pruning removed + $N_{50}P_{20}K_{20}$.

months. Moreover, the decrease in pH with prunings applied + $N_{50}P_{20}K_{20}$ were lower compared to other managements after 12 and 20 months though statistically not significant. Moreover, the decrease in pH with prunings applied + $N_{50}P_{20}K_{20}$ was higher in hedgerow treatment than in the open field treatment. These results indicate a combined effect of pruning biomass and fertilizer on the increase of acidity. Even after continuous biomass application for 20 months, pH values were still below 5.

In the open field system, the $N_{50}P_{20}K_{20}$ designed subplot had significantly lower initial bulk density than the $N_0P_0K_0$ designed subplot (Table 5). There was no significant effect of management in the hedgerow and the open field systems after 12 months. But an exception was found in *Cassia spectabilis* and *Stylosanthes guyanensis* treatments which had significantly lower bulk density with prunings applied + $N_{50}P_{20}K_{20}$ than other managements. This result suggests the presence of a pruning biomass effect. The change over time was not significant in *Stylosanthes guyanensis* (0.87 to 0.84) while it was significant in *Cassia spectabilis* (0.91 to 0.82). The *Gliricidia sepium* hedgerow with prunings applied + $N_0P_0K_0$ treatment had significantly lower bulk density compared to the other hedgerow treatments. But, there was no significant difference in bulk density among the managements after 12 months indicating no effect of pruning biomass. The result of lower bulk density in *Cassia* systems strongly indicates the loosening of soil due to addition of organic matter through the application of prunings and residues.

Highest organic C (9.2 t ha^{-1}) was added from prunings, crop residues and crop roots (50% of dry matter) of the *Cassia spectabilis* system, while the lowest was from the open field system (4.3 t ha^{-1}) with prunings applied + $N_{50}P_{20}K_{20}$ (Table 6). But the systems lost all the added carbon and even the initial soil content was reduced. An exception was observed in the open field

Table 5. Bulk density (g ml^{-1}) changes (0–15 cm, topsoil) as affected by alternative management practices and hedgerow system on sloping acidic land at Cavinit, Laguna, Philippines.

Species	Management practices					
	Initial			After 12 months		
	M1	M2	M3	M1	M2	M3
OF	0.93	0.86	0.86	0.87	0.85	0.84
GS	0.90	0.88	0.89	0.81	0.84	0.85
PP	0.88	0.85	0.85	0.89	0.88	0.84
SG	0.90	0.87	0.87	0.91	0.84	0.86
CS_a	0.92	0.91	0.91	0.92	0.82	0.89

Comparison	SED	LSD (5%)
2-Time means at each Management × Species	0.037	0.081
2-Management means at each Time × Species	0.031	0.064
2-Species means at each Time × Management	0.035	0.074

OF = Open field system, GS = *Gliricidia sepium*, PP = *Pennisetum purpurem*. SG = *Stylosanthes guyanensis*, CS = *Cassia spectabilis*.
M1 = pruning applied + $N_0P_0K_0$; M2 = pruning applied + $N_{50}P_{20}K_{20}$; M3 = pruning removed + $N_{50}P_{20}K_{20}$.

Table 6. Expected organic carbon, nitrogen and phosphorus dynamics in the soil pool (0–15 cm) after 20 months as affected by hedgerow species and management.

Species and management	Org. C. (t ha^{-1})			N (t ha^{-1})		Avail. P (t ha^{-1})	
	Addition	System loss/grain	Soil degradation/ improvement	Addition	System loss/grain	Addition	System loss/grain
Open field							
$N_0P_0K_0$	3.3	–6.7	–3.4	81	–748	4.9	5.6
$N_{50}P_{20}K_{20}$	4.3	–3.8	0.50	200	–398	46.4	–27.4
G. sepium							
M1	4.7	–13.4	–8.90	153	–1071	10.8	4.2
M2	6.0	–10.1	–4.10	283	–730	53.2	–25.7
M3	3.7	–10.1	–6.42	192	–1015	46.1	–32.6
P. purpureum							
M1	6.9	–18.4	–11.50	163	–1457	16.4	1.2
M2	8.6	–14.1	–5.50	297	–938	61.5	–34.1
M3	3.4	–12.1	–8.70	183	–1295	45.7	–45.2
S. guyanensis							
M1	4.7	–10.9	–6.20	150	–749	11.2	5.1
M2	5.9	–12.2	–6.40	277	–859	53.4	–33.1
M3	4.3	–9.1	–4.90	206	–726	47.2	34.8
C. spectabilis							
M2	9.2	–11.3	2.10	504	–1076	64.4	–27.6

M1 = Prunings appled + $N_0P_0K_0$; M2 = Prunings applied + $N_{50}P_{20}K_{20}$; M3 = Prunings removed + $N_{50}P_{20}K_{20}$.
Addition = Prunings + Crop residues + Fertilizers.
System loss/gain = Apparent system total (Initial soil content + Addition) – Actual soil content – Plant uptake (for N and P).
Soil degradation/improvement = Actual soil content after 20 months – Initial soil content.

system with $N_{50}P_{20}K_{20}$ treatment which enriched the soil by 0.5 t ha^{-1} losing 3.8 t ha^{-1} of the added carbon.

Among the hedgerows, *Cassia spectabilis* with prunings applied + $N_{50}P_{20}K_{20}$ had the lowest degradation in soil organic C (2.1 t ha^{-1}) followed by *Gliricidia sepium* (4.1 t ha^{-1}). This is the reason why the decrease in per cent organic C from the initial level was less in *Cassia spectabilis* system than that in the others (Table 4a). Highest degradation occurred with prunings applied + $N_0P_0K_0$ of *Pennisetum purpureum* (11.5 t ha^{-1}) among all the systems. The extent of carbon loss was comparatively low with prunings applied + $N_{50}P_{20}K_{20}$ of all the hedgerows where high carbon was added to the soil. The results showed the tendency of combined effect of biomass and fertilizer on the replenishment of soil organic carbon.

The results of soil N balance revealed that the losses through mechanisms other than plant uptake were higher than addition (Table 6) regardless of the treatments. Apparently lowest amount of nitrogen (398 kg ha^{-1}) was lost other than plant uptake with $N_{50}P_{20}K_{20}$ of the open field system which was followed by *Gliricidia sepium* (730 kg ha^{-1}). This result indicates that the utilization of added nitrogen through prunings in the hedgerow system was low.

The status of available P is interesting because soil enrichment occurred in spite of system losses other than plant uptake (Table 6). This was particularly high with prunings applied + $N_{50}P_{20}K_{20}$ treatment of all the hedgerow treatments. Highest net gain of available P (14.9 kg ha^{-1}) was obtained with prunings applied + $N_{50}P_{20}K_{20}$ of *Cassia spectabilis* among the treatments mainly due to highest contribution of P from prunings.

Discussion

The input that mainly determines the variation among the hedgerow species in nutrients added to the soil is the in situ pruning biomass production. The results shown in Table 2 indicate the limiting growth nature of *Gliricidia sepium* compared to *Cassia spectabilis*; hence, the non-N-fixing tree legume (*Cassia*) exerts an advantage over the N-fixing tree legume (*Gliricidia*) under acidic soil. The higher pruning dry matter of *Cassia spectabilis* compared to *Gliricidia sepium* is in agreement with the report of Maclean et al. (1992) under acidic soils. Higher N contribution of *Cassia* prunings than of *Gliricidia* corroborates the findings of Garrity and Mercado (1994). There was stunted growth and development of *Gliricidia sepium* in the present study. Strong acidity (Table 4d) may have caused this poor of performance. This proposition may also be attributed to low P availability (Table 4c) in soils which is required for the N fixation process. Szott (1987) observed that the exchangeable cations (K, Ca, Mg) and phosphorus declined over time in alley cropping systems under acidic conditions. Sufficient Ca base is necessary for the nodulation process (Munns, 1978). These are the reasons why N_2-fixing trees cannot grow well in acidic soils.

Grain yields of rice and cowpea were reduced due to installation of a hedgerow barrier compared to open field systems; this reduction was, however, compensated by the continuous application of pruning biomass along with inorganic fertilizers. As the basic need of society (food grains) is the prime focus in alley cropping systems, the maintenance of crop yield in alleys over a period of time is important.

The result of rice yield reduction in all the hedgerow treatments with prunings removed + $N_{50}P_{20}K_{20}$ strongly correlates with the findings of Fernandes et al. (1993) and Garrity et al. (1992) on acidic soils. The compensation of yield reduction by the application of pruning biomass partially confirmed the results of Szott (1987). He observed that increased rates of pruning application were able to partially compensate for the yield reduction.

The maintenance of crop yield is not the only concern, but soil fertility is also a crucial issue for updating sustainability attributes of a land use system. Organic carbon, N and P dynamics over three crops (rice–cowpea– rice) further confirmed that in situ pruning biomass without fertilizer was not sufficient to maintain their levels in the soil. The same conclusion was reached by Szott et al. (1991) for an alley cropping system under acidic condition. The application of fertilizer together with pruning biomass minimized the extent of soil degradation and even increased the level of soil phosphorus. Crops can benefit more from the indirect contribution of pruning biomass than the direct contribution through nutrients.

The result in the reduction of soil organic carbon is in partial agreement with Lal (1989) in *Leucaena* + maize and *Gliricidia* + maize system over five years of cultivation under acidic soil. Our finding also supports the results of Ojeniyi and Agbede (1980) who found a slight reduction in organic C in the intercropping of *Gmelina* with food crops. It was assumed that the shading of *Gmelina* might have caused faster decomposition of organic matter through promoting microbial activity. During decomposition of organic matter, carbon was oxidized to CO_2 which caused reduction in organic carbon. Moreover, there was a modest residual contribution of organic carbon because of the short term (20 months) of the present study.

The present finding (Table 4c) indicates that available P in soil declined in alley cropping systems without inorganic fertilizers. This is in agreement with the findings of Szott (1987), most likely because of the insufficient recycling of P from pruning biomass. The higher phosphorus availability over 20 months compared to that over 12 months was mainly due to a single rice crop grown after 12 months compared to two crops (rice and cowpea) during 12 months. However, the amounts of P fertilizer (20 kg ha^{-1}) was the same for rice–cowpea and only rice. The higher decrease in soil pH over time in the hedgerow system compared to the open field strongly agrees with the result of Soriano (1991). The application of pruning biomass and inorganic fertilizers (urea, TSP and MP) together contributed more to this decline than the other managements. Pruning biomass could release an enormous amount of

H^+ ions upon dissociation of the carbonic acid during its decomposition and thereby increase acidity. The mechanism is that microbial decomposition of organic matter produces CO_2, which reacts with H_2O to form carbonic acid (IRRI, 1978). Moreover, urea is known to have an acidifying effect on soils (Mengel and Kirkby, 1987). The acidifying effect of urea in the soil was observed by Szott (1987) and Daland et al. (1993) through their work in the alley cropping system. However, the general decline in soil pH after 12 months regardless of management and hedgerow species may be attributed to exudation of H^+ from cowpea roots. For plants which fix N symbiotically, the available evidence shows that about 1 meq of H^+ is exuded per of plant dry weight (Israel and Jackson, 1978). Cowpea is a symbiotic N-fixation crop; thus, if the source of N is NH_4^+ or N_2 fixed, they absorb more cations than anions and excrete H^+ (Nye, 1984). If plants absorb N in the form of NO_3, in general they absorb more anions than cations and excrete HCO_3 to maintain electrical neutrality across the root soil interface. Therefore, the general increase in pH after 20 months could be due to excretion of HCO_3 by rice roots in the upland condition.

The significant reduction in bulk density with *C. spectabilis* might give improved permeability, aeration and root penetration. Yamoah et al. (1986) found a decrease in bulk density in alley cropping with *Leucaena*, *Flemingia and Gliricidia* in Nigeria and suggested that good physical properties may even be more important than the supply of nutrients. If the root development is affected due to a poor physical condition, nutrients released from prunings cannot be taken up by the plants properly and, therefore, this nutrient supply becomes useless. Moreover, the direct contribution of prunings for nutrients was affected by competition between the hedge and the crop. The degree of competition for nutrients, however, varied among the hedgerow species. It was high in *Pennisetum purpurem* which was followed by *Cassia spectabilis* (Table 3) in terms of reduction of alley crop yields.

Conclusion

From the overall results, it can be concluded that the *Cassia spectabilis* system performed better than the other hedgerow systems in maintaining a higher level of pruning biomass, crop yield, and soil resources under high external input conditions.

It is important to note that the hedgerow system is not sustainable on sloping acidic lands without the addition of inorganic fertilizers, and even then some soil quality degradation can be expected. The reasons are mainly due to low native fertility of the soil and inadequate recycling of nutrients from the prunings. Therefore, an integrated nutrient management approach, i.e. pruning biomass combined with inorganic fertilizers, is imperative to conserve soil resources and maintain crop productivity over time in contour hedgerow systems in environments similar to those studied here.

The residual effects of continuous application of pruning biomass may be underestimated due to the short-term experiment (20 months). Therefore, such trials should be continued for at least three to five years so that the long-term effects on soil changes and crop yield can be determined.

To minimize the losses of soil resources, especially nitrogen and organic carbon, research on management techniques should be conducted. Growing fast and slowly decomposing hedges alternately can maintain more synchrony between the supply and the crop's demands. Performance of these alternating hedges on long-term N-dynamics (recovery and losses) should be tested. Moreover, selection and improvement of acid-tolerant hedgerow species should be continued.

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