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Grain crop response to contour hedgerow systems on sloping Oxisols

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Abstract. Farming systems that minimize the rate of soil degradation and optimize food crop yields are needed to sustain soil productivity on sloping, acid, infertile soils in the humid tropics. Research was conducted on two Oxisols with slopes ranging from 22 to 30% to evaluate the performance of several contour hedgerow systems, with and without the addition of 60 kg N ha^{-1} per crop, on rice (*Oryza sativa*) and maize (*Zea mays* L.) production. Contour hedgerows were double rows of the tree legume *Gliricidia sepium* (G); *Gliricidia* and the native grass *Paspalum conjugatum* (GPas); *Gliricidia* and an exotic fodder grass *Penisetum purpureum* (GPen); double rows of *Penisetum* (Pen); and a conventional open field (C) farming system without hedgerows. *Gliricidia* prunings and all crop residues were applied to the soil surface in the alleys, but *Penisetum* was harvested. Food crop yields in all hedgerow treatments tended to be less than the Control for the first two years, presumably due to the displacement of land planted to the food crop. In the third and the fourth years, the rice and maize yields of Treatments G and GPas exceeded the Control, most consistently when N was not applied. *Penisetum* reduced food crop yields regardless of N application presumably due to nutrient removal in the fodder. The results indicate that *Gliricidia* in a contour hedgerow increases food crop yield on strongly acid Oxisols by recycling nutrients and partially supplementing the N demand by the food crops.

Introduction

Intensive cereal-based farming systems on sloping, acid, infertile soils are widely practiced in the humid tropics (Garrity, 1993). In the absence of soil and water conservation measures, soil productivity decreases in these unstable systems due partially to accelerated soil erosion. Both national and international agencies are attempting to focus research to develop viable cropping systems for sloping lands. Effective systems must minimize soil erosion while sustaining or increasing food production. Agroforestry approaches to soil management may be useful for these marginal, sloping land environments.

A ‘contour hedgerow system’ is an alley cropping system where the hedgerows are planted on the contour on sloping land. Hedgerows spaced at close intervals facilitate terrace formation as soil from a higher elevation is collected behind the hedgerow at a lower elevation (Nair, 1984). Terrace formation occurs rapidly after contour hedgerows are planted. Animal-drawn moldboard plowing contributes to significant terrace formation during the first two years after establishment of contour hedgerows (IRRI, 1989).

Both favorable and unfavorable effects on the food crop occur when the food crop is grown in the alleys between closely spaced rows of trees or grasses. Favorable interactions may include the addition of organic matter from the hedgerow plants to improve soil physical, biological, and chemical conditions; reduction in soil erosion; and harboring of beneficial predators in the hedgerows. Unfavorable interactions may include the displacement of a fraction of the land area from food crop production to the hedgerow crop; competition by the hedgerow and the food crop for light, nutrients, and water; allelopathy; and harboring harmful pests and diseases by the hedgerows (Lal, 1991; Kang et al., 1990). Because of these complex interactions, Young (1987a and 1987b) suggested that alley cropping be limited in the densely populated, humid and subhumid areas dominated by moderate to steep slopes, where soil erosion is rapidly degrading the land.

Because pruned hedgerows take land out of food crop production, either the food crop yields must become significantly higher, or byproducts such as nitrogen must be provided by the hedgerow crop to compensate for the extra labor required (Lal, 1989). For example, *Gliricidia sepium* (Jacq.) is a N-fixing species frequently used in alley cropping systems (e.g., Maclean et al., 1992a and b; Evensen, 1989; Fernandes, 1990; Salazar and Palm, 1987). In the high-base status soils in Nigeria, *Gliricidia* and *Leucaena leucocephala* induced high food crop yields, but *Leucaena* was devastated by the psyllid pest, *Heteropsilla cubana*. Favorable characteristics which make *Gliricidia* a good candidate for a hedgerow crop are its ability to coppice vigorously, ease of establishment by cuttings, and N-fixing ability (Kang et al., 1990; Ladha et al., 1993).

Several grasses, either singly or in combination with a tree species, have been proposed as possible hedgerow plants (Garrity et al., 1993). *Penisetum purpureum* Schumach. (napier grass) is an exotic, fast-growing species that attains a height of 2 to 3 m. This grass must be cut regularly to minimize shading of the accompanying food crop. *Penisetum* grown in hedgerows is intended to provide erosion control as well as a source of fodder for ruminants. *Paspalum conjugatum* (bahia grass), a grass common to the Philippines, is palatable to ruminants, but produces less biomass compared to other sources of fodder. *Paspalum* is ideal for erosion control because it forms a thick vegetative mat and rarely needs to be cut because its maximum height is 40 cm. In addition, it is shade tolerant and can be used in combination with a tree species in a hedgerow.

All plants have certain ecological niches in which they perform well. Recent work has raised concerns about the viability of hedgerow intercropping on strongly acid soils found throughout much of the humid tropics (Szott et al., 1991; Garrity, 1993 and 1996; Fernandez, 1990; Evensen, 1989). The deep tree rooting patterns observed on higher base status soils may be inhibited by the high exchangeable Al concentration in the subsoil of Ultisols and Oxisols. Nitrogen and phosphorus deficiencies are common in such soils. Furthermore, shallow rooting may promote intense root competition between the annual food crop and the perennial hedge for nutrients and water in the surface soil layer. On the other hand, the organic matter inputs of the leguminous tree hedgerow prunings provide some nitrogen and phosphorus resources to the food crops grown in the alleys (Basri et al., 1990).

The objective of this study was to evaluate the interactive effects of contour hedgerow systems and N application on food crop production and soil erosion on sloping Oxisols. Crop response variability within the alley ways was also evaluated to elucidate a better understanding of the complex interactions of the system.

Materials and methods

The experiment was conducted from June 1988 to December 1992 on two acid, upland sites in two farmers' fields at the outreach station of the International Rice Research Institute (IRRI) in Claveria municipality, Misamis Oriental province, Mindanao, the Philippines (8°38′ N, 124°55′ E). The soil at the Compact site (500 m elevation and 1880 mm annual rainfall) is a very-fine, halloysitic, allic, isohyperthermic, Typic Hapludox and the soil at the Cabacungan site (200 m elevation and 1200 mm annual rainfall) is a very-fine, kaolinitic, isohyperthermic, Rhodic Hapludox (H. Subagjo, 1993, personal communication). Selected soil properties from two soil pits adjacent to the two experimental sites are given in Table 1.

The hedgerow systems evaluated were: Control (conventional open-field system, i.e., without contour hedgerows) (C); double rows of the pruned tree legume *Gliricidia sepium* (G); one row of *Gliricidia* and one row of native pasture grass *Paspalum conjugatum* (GPas); one row of *Gliricidia* and one row of *Penisetum purpureum* (GPen); and double rows of *Penisetum* (Pen).

The main plot treatments were arranged in a randomized complete block design with two blocks at each of two sites. Each hedgerow main plot was split into two N (as urea) subplots: no N added and 60 kg N ha^{-1} per crop applied in split applications. The first 30 kg ha^{-1} of N was applied 2 wk after crop emergence and the remaining N was applied 2 wk later. In the late wet season of 1991, however, the soil was so dry that the second N application was not done.

Each hedgerow plot had 5 hedgerows and 4 alleys. The width of each main plot along the contour was 15 m and its length downslope ranged from 18 to 22 m, depending on slope which ranged from 22 to 30%. The distance between adjacent hedgerows was based on a 1-m change in elevation and, on the average, was 5.5 m. Average hedgerow width was 0.8 m and average alley width was 4.7 m, thus about 15% of the total land area was devoted to hedgerows.

Table 1. Soil profile properties at the Compact and Cabacungan sites, Claveria, Mindanao, the Philippines.

Soil depth	Horizon	Exchangeable				Sum[a]	pH in HOH	Bray-2 P	C	N
		K	Ca	Mg	Al					
		—— cmol(+)kg^{-1} ——						mg kg^{-1}	— g kg^{-1} —	
Compact site										
0–14	A	0.33	1.30	0.54	1.09	3.56	4.5	3.2	13	1.3
14–31	AB	0.04	0.62	0.23	2.26	3.55	4.7	2.4	5	0.6
31–85	Bo1,2	0.04	0.09	0.10	2.86	3.44	4.8	2.8	4	0.4
85–143	Bo3,4	0.04	0.05	0.08	3.18	3.68	4.6	2.0	4	0.4
Cabacungan site										
0–6	A	0.12	2.56	0.13	0.82	3.94	4.8	4.3	18	1.6
6–28	AB	0.09	0.53	0.13	1.36	2.43	4.5	0.2	7	0.9
28–83	Bo1,2	0.03	0.60	0.15	1.44	2.53	4.8	0.2	5	0.6
83–116	Bo3	0.02	0.44	0.08	1.52	2.40	5.0	0.2	4	0.4
116–151	Bo4	0.03	0.11	0.07	2.07	2.61	5.3	0.2	3	0.3

[a] Sum of exchangeable K, Ca, Mg, and Al.

For Treatment G, *Gliricidia* was planted in two rows using 40-cm-long branch cuttings with a diameter of 2 to 3 cm. The row spacing and tree spacing within rows were 30 cm. For Treatments GPas and GPen, *Gliricidia* was planted in a row on the 'uphill' side of the hedgerow while grass tillers (*Paspalum* or *Penisetum*) were planted at 30-cm spacings in a parallel row 30-cm 'downhill' from the *Gliricidia* plantings. The *Gliricidia* and *Penisetum* species were pruned two times during each rainy and dry season. The first pruning occurred 1 wk after the food crop was planted; the second, 6 to 12 wk later. *Paspalum* was not pruned due to its short stature. The pruned *Gliricidia* biomass was weighed and uniformly spread on the soil surface in the alleys while the *Penisetum* clippings were removed from the plots for livestock feed to simulate the local practice. Plant residues from each food crop remained on the plot area as mulch.

Prior to hedgerow establishment in 1988, the land at both sites was under fallow rotation. Two crops were planted each year. In 1989 and 1990 maize (*Zea mays*) was grown during the early wet season (May to October) and rice (*Oryza sativa*) during the late wet season (October to February). Rice (cv IR-30716-B-1-B-1-1-2) was drill-seeded at 100 kg seed ha^{-1} in rows 30 cm apart. Maize (cv Pioneer 3274) was planted at 25 kg seed ha^{-1} in rows 60 cm apart; plant spacing within the row was 20 cm. In the wet season of 1991, rice and maize were planted on 13 May on alternate alleys to observe their productivity in direct simultaneous comparison. The planting dates for late wet season 1991 maize were 10 and 29 Oct.; for rice in wet season 1992 were 1 and 2 June; and for maize in late wet season 1992 were 26 Oct. and 2 Nov. for the Compact and Cabacungan sites, respectively. The alleys for all hedgerow treatments and the entire plot for Treatment C were plowed twice with an oxen-pulled moldboard plow and harrowed once with an oxen-pulled wooden harrow before planting each crop.

At planting, each crop received 20 kg P ha^{-1} as triple super phosphate and 20 kg K ha^{-1} as KCl. These fertilizers were drilled near the plant rows. Dolomitic lime at a rate of 3 t ha^{-1} was incorporated into the 0- to 15-cm soil depth in 1990 before planting rice. The rates of fertilizer and lime applications for the hedgerow treatments were based on the alley area while for Treatment C, they were based on the entire plot area.

Harvest data for each crop were collected from 4-m segments of each row in alleys 2 and 3. Grain yield data are reported based on 0.14 g g^{-1} water content. For testing the main plot treatment effects, rice and maize grain yields were calculated in t ha^{-1} of total land area (alley plus hedgerow). The experiment consisted of two locations L, two replications nested in the two locations R(L), five hedgerow Treatments T as the main-plot factor, and two fertilizer nitrogen levels N as the sub-plot factor. The total number of rows for each alley was used as a covariate to evaluate alley size on crop yield (a narrower alley has more crop-alley interface).

Competition between the food crop and hedgerow is a primary issue in evaluating contour hedgerow systems. One approach to evaluate the competition effect is to compare the yield response from the first few rows adjacent to the hedgerow to the yield response at rows further away from the hedgerows. Accordingly, for maize, three rows adjacent to the upper hedgerow and three rows adjacent to the lower hedgerow were designated. For rice, the same procedure was followed except that yields from five rows adjacent to each of the upper and lower hedgerows were included (Figure 1).

Surface water runoff and soil loss were measured for the Control and the GPas treatments from Dec. 1991 to Nov. 1992. Limited resources allowed the installation of only 8 runoff plots, two replicates of two treatments per site. A 5-m wide strip running the full downslope length of Treatments C and GPas was separated from the rest of the plot with galvanized sheet metal barriers. Each 20-cm-wide sheet metal barrier was inserted 12 cm into the soil at the upper end and at both sides of the runoff plot. During heavy rains, runoff water and suspended solids flowed into a gutter placed at the lower plot boundary. Soil particles and aggregates were trapped in the gutter, and runoff water and suspended solids flowed into a tipping bucket device for which the number of tips was mechanically counted. The volume of runoff and the oven-dry mass of sediment collected in the gutter was measured after each rain.

Results and discussion

Rice yield data are available for four years (1989 to 1992) and maize yield data are available for two years (1991 to 1992). Because of several crop

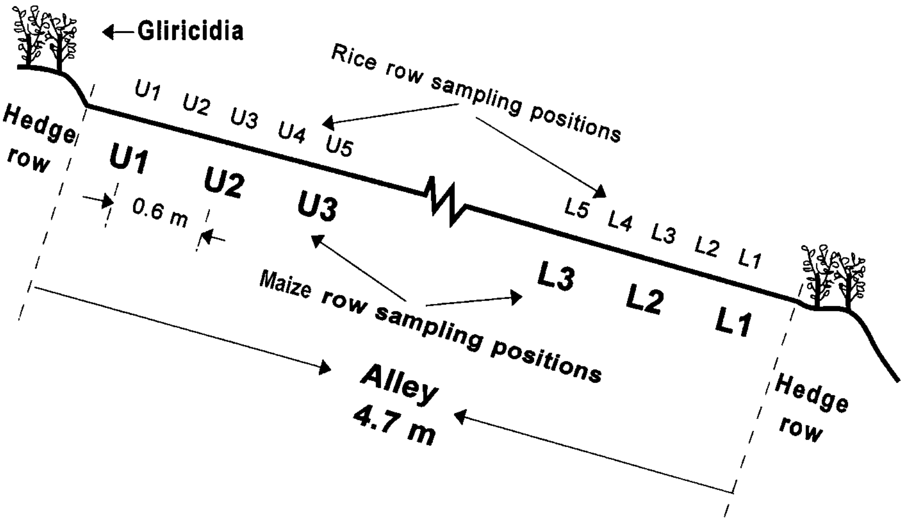

Figure 1. Schematic cross sectional representation of maize and rice grain yield sampling position for treatments with hedgerows, Mindanao, the Philippines (U refers to upper rows; L refers to lower rows).

failures in Cabacungan (due to the dry period which usually occurs in August or September and coincides with the panicle initiation stage of rice), the only year with acceptable rice yield data for both locations was 1989 (Table 2). Corn yield data from both locations are available for the 1991 wet season and the 1992 late wet season (Table 3). In most cases, crop yields tended to be greater in Compact than in Cabacungan, probably a result of higher rainfall in Compact.

Covariance analysis (not shown) of yield data using the number of food crop rows within alleys as the covariate was not significant ($P > 0.30$) for any of the seven crops. Based on this result, inclusion of the covariate did not improve the efficiency of the analysis, thus the following analyses were run without the covariate.

Treatment effects

In 1989, mean rice yields were about 20% less for the hedgerow systems corresponding to the approximately 15% reduction in area planted to rice. Rice yields in 1990 were low due to drought stress during panicle initiation in August. Yields for the hedgerow treatments receiving no N fertilizer were comparable to those for Treatment C. In 1991 and 1992, a few treatments with *Gliricidia* as a hedgerow exceeded yields of Treatment C when no N was applied. In 1992, for 0-kg N, the hedgerow treatments involving *Gliricidia* had a greater yield (2.4 t/ha) than Treatment C (1 t/ha). However, the Pen treatment reduced yield regardless of N level and the reduction was relatively greater in 1992 than in 1991 (Table 2).

Table 2. Rice grain yield as affected by contour hedgerow system and N level. Yields were based on total land area (alley + hedgerow), Mindanao, the Philippines.

Treatment	N (kg ha^{-1})	
	0	60
	t ha^{-1}	
1989 (Compact and Cabacungan)		
Control (C)	1.94 a*	2.41 a
Gliricidia (G)	1.19 b	2.01 ab
Gliricidia+Paspalum (GPas)	1.53 b	1.36 b
Gliricidia+Penisetum (GPen)	1.34 b	2.20 a
Penisetum (Pen)	1.62 ab	2.17 a
1990 (Compact)		
Control (C)	0.76 a	1.31 a
Gliricidia (G)	0.60 a	0.92 b
Gliricidia+Paspalum (GPas)	0.91 a	1.02 b
Gliricidia+Penisetum (GPen)	0.75 a	0.96 b
Penisetum (Pen)	0.54 a	0.67 c
1991 (Compact)		
Control (C)	1.75 b	3.21 a
Gliricidia (G)	2.53 a	3.35 a
Gliricidia+Paspalum (GPas)	2.25 a	2.74 a
Gliricidia+Penisetum (GPen)	1.50 b	2.86 a
Penisetum (Pen)	1.42 b	2.01 a
1992 (Compact)		
Control (C)	1.01 b	3.38 a
Gliricidia (G)	2.39 a	2.57 ab
Gliricidia+Paspalum (GPas)	1.54 b	3.09 a
Gliricidia+Penisetum (GPen)	1.57 b	2.20 ab
Penisetum (Pen)	0.80 c	0.62 c

For a given year within a given column, means followed by the same letter are not significantly different as tested with LSD at $\alpha = 0.10$. For 1989, the effect of nitrogen application is significant at $\alpha = 0.10$ and for other year it was significant at $\alpha = 0.05$.

Maize grain yield for Treatments G and GPas was similar to or higher than the yield for Treatment C. Maize yield for Treatments Pen and GPen in 1992 was less than the Control regardless of N level. Yield on Treatment Pen was the lowest (Table 3).

Nitrogen fertilization consistently increased rice and maize yields (Tables 2 and 3). When N was applied, no hedgerow treatment with *Gliricidia* outyielded the control, except for maize in the late wet season in 1991, indicating in general that the N fertilizer substituted for the effect of *Gliricidia*. The soil was so dry during this season that only half of the N for the 60-kg N ha^{-1} subplots was applied.

Under complete fertilization, food crop yields in the contour hedgerow systems were generally less than or equal to the Control. Lal (1991), citing several alley cropping studies from Africa, Latin America, and Asia, stated

Table 3. Maize grain yield as affected by contour hedgerow treatments and N level. Yields are based on total land area, Mindanao, the Philippines.

Treatment	N (kg ha^{-1})	
	0	60
Wet season 1991 (Compact and Cabacungan)	t ha^{-1}	
Control (C)	2.04 ab*	3.80 a
Gliricidia (G)	3.06 a	4.06 a
Gliricidia+Paspalum (GPas)	2.75 a	3.48 a
Gliricidia+Penisetum (GPen)	1.92 ab	3.36 ab
Penisetum (Pen)	1.20 b	2.48 b
Late wet season 1991 (Compact)		
Control (C)	0.56 b	0.88 b
Gliricidia (G)	1.20 a	1.73 a
Gliricidia+Paspalum (GPas)	0.81 ab	1.07 b
Gliricidia+Penisetum (GPen)	0.70 ab	1.11 b
Penisetum (Pen)	0.45 b	0.80 b
Late wet season 1992 (Compact and Cabacungan)		
Control (C)	0.95 b	2.04 a
Gliricidia (G)	1.63 a	2.31 a
Gliricidia+Paspalum (GPas)	1.07 ab	1.96 a
Gliricidia+Penisetum (GPen)	0.66 c	1.57 b
Penisetum (Pen)	0.25 d	0.92 c

* For a given year within a given column, means followed by the same letter are not different as tested with LSD at $\alpha = 0.20$. The effect of nitrogen application is significant at $\alpha = 0.05$. Only 30 kg N ha^{-1} was applied (first application) in late wet season 1991 due to a very dry weather.

that hedgerow prunings applied to the soil in conjunction with fertilizer application had no further effect on food crop yields. In the absence of N fertilizer, the contour hedgerow treatments, especially Treatments G and GPas, often had higher yields than Treatment C, with Treatment G usually having the highest yield. Beginning in 1990, grain yield was least for Treatment Pen. This was associated with competition for water (Agus et al., 1997) and removal of the *Penisetum* clippings and nutrients (especially K as much as 19 kg ha y^{-1}).

Several of the above statements are not supported by consistent statistical tests at $\alpha = 0.10$. However, the tendencies discussed above are sufficiently consistent that we feel the data across the four harvests are revealing predictable patterns.

Variation in crop yield

Maize yields in the 1991 wet season versus row number are presented in Figure 2 (row positions are defined in Figure 1). Maize yield, averaged across all four hedgerow treatments, was lower in the upper half of the alley than in

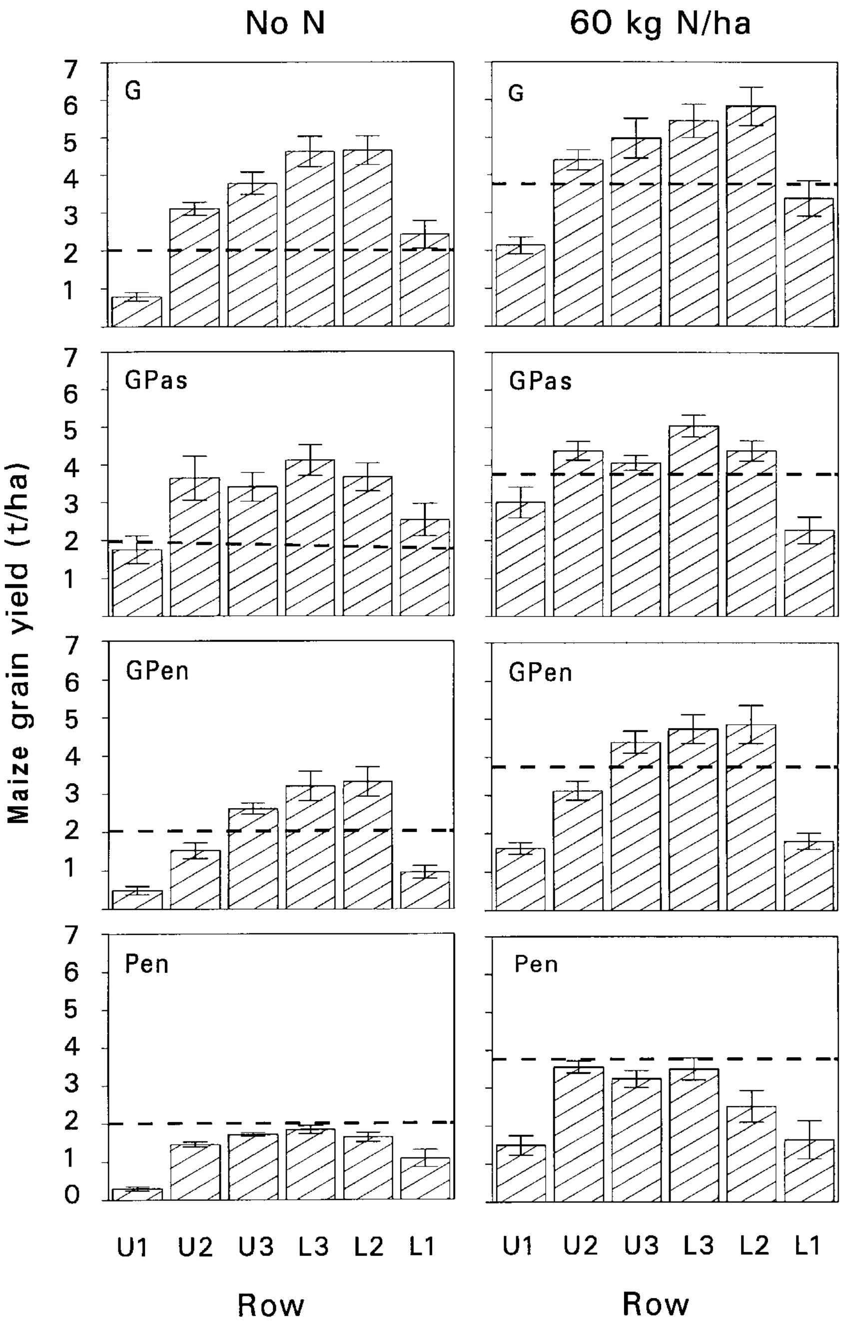

Figure 2. Maize grain yield as a function of row number in the 1991 wet season. Refer to Figure 1 for the definition of row sampling positions. Dashed lines across bars represent yield for Treatment C, Mindanao, the Philippines.

the lower half ($P < 0.05$). Rice grain yields followed the same tendency (Figure 3), but the difference was less consistent. Collectively, the yield results indicate that the growing environment at the lower part of the alley was more favorable than at the upper part of alley. The difference was more pronounced for maize (Figure 2) than for rice (Figure 3). We believe these productivity gradients to be due to the thicker Ap horizon, and consequently to more favorable soil physical and chemical conditions on the lower part of the alley. Organic C, Bray-2 P, soil pH, and exchangeable Ca increased and exchangeable Al decreased from the upper to the lower alleyway positions (Agus, 1993).

The maize and rice yields in the middle of the alley were significantly higher than the yield in rows adjacent to the hedgerows. The yields on rows adjacent to hedgerows could not exceed the yield of Treatment C. For Treatments Pen and GPen rice yields barely exceeded the yield of Treatment C in all rows tested. Among possible causes of crop suppression in the vicinity of the hedgerows is the competition by the hedgerow food crops with the alley crops for water and nutrients. Monteith et al. (1991) studied an alley cropping system in India using *Leucaena leucocephala* as the hedgerow crop and pearl millet (*Penisetum glaucum*) as the alley crop and concluded that above-ground competition was minimal compared to below-ground competition. Systematic pruning of the above-ground vegetation in the present study was presumed to minimize competition for light.

Treatment effect on soil loss

The range of tolerable erosion (T value) as suggested by Wischmeier and Smith (1978) is between 2 and 11.2 t ha^{-1} y^{-1} (equivalent to 0.2 to 1.12 mm soil y^{-1} for soils with a bulk density of 1.0 t m^{-3}) depending on soil susceptibility to erosion. Soil loss for both sites exceeded this limit, especially for Treatment C (Table 4). The GPas hedgerow reduced soil loss by 67% at the Compact site and by 77% at the Cabacungan site.

Twenty nine of the 121 rains at the Compact site caused soil loss for Treatment C, while only 17 rains caused soil loss for Treatment GPas. For 76 rains at the Cabacungan site, soil loss was recorded for 14 rains in Treatment C and 11 for Treatment GPas. These rains usually occurred from June through September, a critical time, especially for Treatment C, because the soil had little vegetative cover. Sparse corn stover from the previous harvest was the only ground cover for Treatment C. The GPas Treatment had a cover of *Gliricidia* prunings in addition to the crop residue.

Sediment trapped in the runoff collector is the major portion of total soil loss. The suspended solids, those solids remaining suspended in the water as it leaves the runoff collector, were 4 to 25% of the total soil loss. This material can be transported further down slope, with some part of it reaching off-farm sites.

In an area with 1279 mm annual rainfall in Rwanda, König (1992) con-

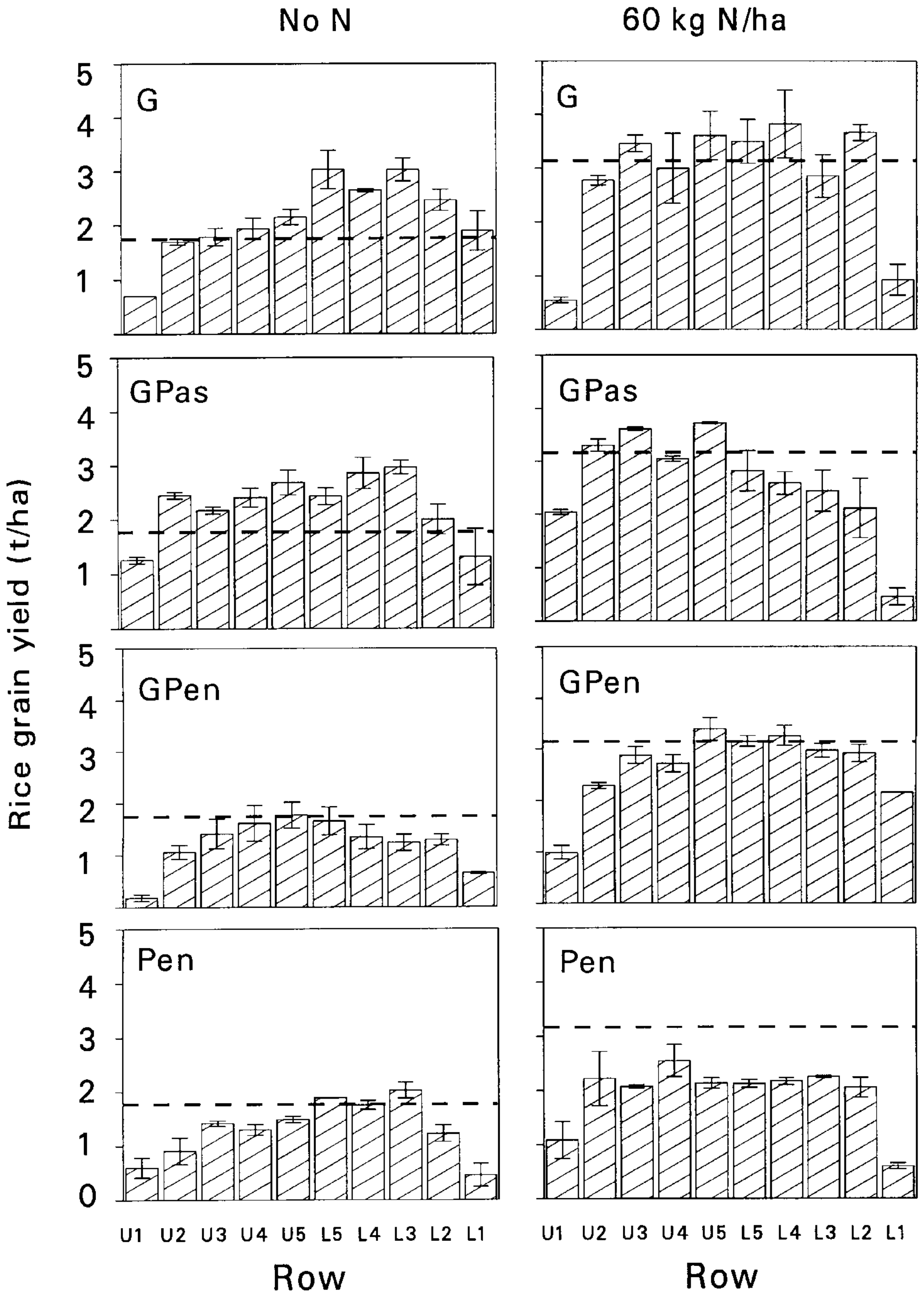

Figure 3. Rice grain yield as a function of row number in the 1991 wet season, Mindanao, the Philippines. Refer to Figure 1 for the definition of the row sampling positions. Dashed lines across bars represent yield for Treatment C.

Table 4. Rainfall, number of rainy days, runoff, and sediment loss for Treatments C and GPas in Compact and Cabacungan from Dec. 1991 to Nov. 1992, Mindanao, the Philippines.

Site	Total rainfall (mm)	Rain events	Treatment	Slope (%)	Total runoff (mm)	Runoff/ rainfall	Soil loss ($t\ ha^{-1}$)
Compact	1520	121	C	23	143	0.09	63
			GPas	21	111	0.07	20
Cabacungan	1249	76	C	30	66	0.05	20
			GPas	27	53	0.04	4

ducted erosion research on a soil with a 28% slope. Mean soil loss from bare soil after 4 years was 557 $t\ ha^{-1}\ y^{-1}$ and from cassava was 303 $t\ ha^{-1}\ y^{-1}$. Hedgerow plots with the tree legumes *Calliandra calothyrsus* and *Leucaena leucocephala*, and the grass species *Setaria splendida*, reduced soil loss to less than 12.5 $t\ ha^{-1}\ y^{-1}$.

Based on this work, we believe that contour hedgerow systems with *Gliricidia,* and probably with *Gliricidia* and *Paspalum,* likely will increase food crop production when N is not applied, at least in the medium term (five years). The addition of N made the positive effect of *Gliricidia* prunings unclear. Contour hedgerows with *Penisetum* may be satisfactory for soil erosion control, but *Penisetum* competes with food crops and when the biomass is removed from the land the soil fertility is depleted, thus reducing food crop yields. Larger nutrient imports will be necessary to balance the nutrient losses in the fodder. *Penisetum* might give results as good as *Paspalum* if the biomass was returned to the field in a manner similar to that of Treatment GPas.

Despite the overall average food crop yield increases in Treatments G and GPas, crop yield suppression was observed in those grain rows near the hedgerows. This and previous studies show that suppression of cereal food crop yields by hedgerows may not be eliminated, but there are opportunities to minimize it. One possible way to minimize the yield suppression is to minimize the length of interface per unit area between the food crop and the hedgerow crops, while maintaining *Gliricidia* biomass production as high as possible. This might be accomplished by increasing both alley and hedgerow widths with more rows of the *Gliricidia* per hedgerow. Widening the alleys translates to longer slopes and less reduction in the slope steepness with the net result being to promote more soil erosion. However, a smaller hedgerow-alley interface likely will increase overall food crop yield per unit area of total land.

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References

Agus F, Cassel DK and Garrity DP (1997) Soil-water and soil physical properties under contour hedgerow systems on sloping Oxisols. Soil and Tillage Research 40: 185–199

Agus F (1993) Soil processes and crop production under contour hedgerow systems on sloping Oxisols. Ph.D. Dissertation, North Carolina State University, Raleigh

Basri I, Mercado A and Garrity DP (1990) Upland rice cultivation using leguminous tree hedgerows on strongly acid soils, p 140. Agron Abstract Amer Soc Agron, Madison, WI

Evensen CLI (1989) Alley cropping and green manuring for upland crop production in West Sumatra. Ph.D. Dissertaton, University of Hawaii, Honolulu

Fernandes ECM (1990) Alley cropping on acid soils. Ph.D. Dissertation North Carolina State University, Raleigh (Diss. Abstr. 91-21993)

Garrity DP (1993) Sustainable land use systems for sloping uplands in Southeast Asia. In: Technologies for Sustainable Agriculture in the Tropics, pp 41–46. Amer. Soc Agron Spec Publ 56, Madison, WI

Garrity DP, Kummer DM and Guiang ES (1993) The Philippines. In: National Research Council. Sustainable Agriculture and the Ecosystem in the Humid Tropics, pp 549–624. NRC, Washington, DC

Garrity DP (1996) Tree-soil-crop interactions on slopes. In: Ong C and Huxley P (eds) Tree-Crops Interactions: A Physiological Approach, pp 299–318. Commonwealth Agricultural Bureaux International, London

International Rice Research Institute (IRRI) (1989) Program report for 1988. IRRI, Los Baños, Philippines, 317 pp

Kang BT, Reynolds L and Atta-Krah AN (1990) Alley farming. Adv Agron 43: 315–359

Kang BT, Wilson GF and Sipkens EL (1981) Alley cropping of maize (*Zea mays* L) and leucaena (*Leucaena leucocephala* Lam) in Southern Nigeria. Plant and Soil 63: 165–179

König D (1992) The potential of agroforestry methods for erosion control in Rwanda. Soil Tech 5: 167–176

Ladha JK, Peoples MB, Garrity DP, Capuno VT and Dart PJ (1993) Estimating diN fixation of hedgerow vegetation using the N-15 natural abundance method. Soil Sci Soc Am J 57: 732–737

Lal R (1989) Soil management options in the tropics as alternatives to slash and burn. Soil Technology 2: 253–270

Lal R (1991) Myths and scientific realities of agroforestry as a strategy for sustainable management for soils in the Tropics. Adv Soil Sci 15: 91–137

Maclean RH, Litsinger JA, Moody K and Watson AK (1992a) Increasing *Gliricidia sepium* and *Cassia spectabilis* biomass production. Agrofor Syst 20: 199–212

Maclean RH, Litsinger JA, Moody K and Watson AK (1992b) The impact of alley cropping *Gliricidia sepium* and *Cassia spectabilis* on upland rice and maize production. Agrofor Syst 20: 213–228

Monteith JL, Ong CK and Corlett JE (1991) Microclimate interactions in agroforestry systems. Forest Ecology and Management 45: 31–44

Nair PKR (1984) Crop Yield Aspects of Agroforestry. ICRAF, Nairobi

Salazar A and Palm CA (1987) Screening of leguminous trees for alley cropping on acid soils of the humid tropics. Proceedings, Workshop on *Gliricidia sepium* (Jacq.) Walp. Management and Improvement, NFTA, Waimanalo, Hawaii and CATIE, Turialba, Costa Rica

Szott LT, Palm CA and Sanchez PA (1991) Agroforestry in acid soils of the humid tropics. Adv Agron 45: 275–300

Wischmeier WH and Smith DD (1978) Predicting rainfall erosion losses – a guide to conservation farming. Agric Handbook No. 537. US Government Printing Office, Washington, DC, 58 pp

Young A (1987a) Soil productivity, soil conservation, and land evaluation. Agrofor Syst 5: 277–292

Young A (1987b) The environmental basis of agroforestry. In: Reifsnyder WS and Darnhofer TO (ed) Meteorology and Agroforestry, pp 29–43. Proceedings, International Workshop of Meteorology to Agroforestry Systems Planning and Management, Nairobi 9–13 Feb, 1987