TROPICAL SOIL MANAGEMENT

Contour Grass Strips and Tillage Affect Corn Production on Philippine Steepland Oxisols

B. B. Thapa, D. P. Garrity, D. K. Cassel,* and A. R. Mercado

ABSTRACT

Cultivated steeplands in the humid tropics require better soil management systems to meet increasing food demands. The objective of this 4-yr study was to evaluate the following four contour soil management systems for corn (*Zea mays* L.) production: (i) contour moldboard plowing (CP); (ii) ridge tillage (RT); (iii) natural grass barrier strips plus moldboard plowing (GCP); and (iv) grass strips plus ridge tillage (GRT). Eight successive corn crops were grown in limed and fertilized soil from 1992 through 1995. On a total land area basis (cropped area plus the area occupied by the grass strips), the 1995 mean grain yields for RT (10.8 Mg ha^{-1}) and GRT (10.3 Mg ha^{-1}) were significantly greater than yields for CP (10.0 Mg ha^{-1}) and GCP (9.6 Mg ha^{-1}). The corn grain yields for the CP and RT systems before 1995 ranged from 1.3 Mg ha^{-1} in 1992 to 8.4 Mg ha^{-1} in 1993, while comparable GCP and GRT yields ranged from 1.4 to 7.6 Mg ha^{-1}. Excluding the area occupied by the grass strips, the GRT system had the highest 4-yr average corn yield (7.3 Mg ha^{-1}) followed by the GCP (7.2 Mg ha^{-1}), RT (6.9 Mg ha^{-1}) and CP (6.7 Mg ha^{-1}) systems. Yields improved during the 1994 and 1995 growing seasons when the grass was not permitted to grow as tall. The combination of contour ridge tillage and contour grass strips has potential for sustaining crop productivity on highly erodible steepland soils in the humid tropics.

Alley cropping or contour hedgerow systems have advantages and constraints (Sanchez, 1995). The technique emerged in the early 1970s for conservation farming on acid, steepland Oxisols and Ultisols in the humid tropics (Kang and Wilson, 1987). Perennial hedgerow plants compete with the alley crop for plant nutrients, light, and water (Buck, 1986). Contour strips of legume shrubs or trees on sloping land can be an effective barrier to water-induced soil erosion in many parts of the tropics (Lal, 1990; Young, 1989; Agus et al., 1997). In the Philippines, Thapa (1991) found that a 1 m wide contour strip of the legume shrub *Desmanthus virgatus* on 14 to 19% slope reduced soil loss by 95% when compared with conventional tillage with a moldboard plow.

B.B. Thapa and D.K. Cassel, Dep. of Soil Science, North Carolina State Univ., P.O. Box 7619, Raleigh, NC 27695-7619; D.P. Garrity, Southeast Asian Regional Res. Programme, Int. Center for Research in Agroforestry, Jln. Gunung Batu No. 5, Bogor, Indonesia; and A.R. Mercado, Int. Center for Research in Agroforestry, Claveria, Phillippines. This research funded jointly by North Carolina State Univ.; Int. Rice Research Inst., Manila, Philippines; and International Center for Research in Agroforestry, Nairobi, Kenya. Support for NC State was provided in part by grant no. DAN-1311-G-1049-00 from USAID. The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service of the products named, nor criticism of similar ones not mentioned. Received 3 Feb. 1999. *Corresponding author (Keith_Cassel@ncsu.edu).

Published in Agron. J. 92:98–105 (2000).

Despite the dramatic reductions in soil erosion (Young, 1989) and substantial amounts of biomass added by perennial hedgerow vegetation (Palm, 1995), crop yields may decline in the alleys without subsequent fertilization, particularly on P-deficient soils (Garrity, 1996). The yield reduction and increased labor required to manage these systems, are dominant issues in the debate about the productivity and sustainability of perennial hedgerow alley cropping systems, especially in acid, infertile soils (Garrity, 1993; Sanchez, 1995). In addition, the use of perennial legume shrub or tree species in alley cropping systems reduces a farmer's flexibility to diversify land use.

The use of contour forage grass strips such as vetiver [*Vetiveria ziganioides* (L.) Nash ex Small] or napier grass (*Pennisetum purpureum* Schumach.) has possibilities for erosion control in Southeast Asia (Lal, 1990). Rapidly growing, tall forage species must be pruned frequently to prevent shading of the alley crops. Also, harvest and removal of fodder for animal feed exacerbated soil nutrient depletion in the vicinity of the hedgerows and crop yields were severely reduced near the forage grass strips (Garrity and Mercado, 1994). An alternative to forage grass strips is the use of indigenous or natural grass strips. Compared with forage strips, natural grass strips may be less competitive, require less labor to install and maintain, and provide excellent erosion control (Garrity, 1993),

Regardless of the kind of contour barrier, a terrace forms with time as soil from the upper part of the alley gradually moves and accumulates in the lower part of the alley near the barrier. Agus et al. (1997) reported terrace formation during a 2- to 3-yr period on an Oxisol in the Philippines after a contour hedgerow alley cropping system was initiated. Tillage contributes to the downslope soil movement and the formation of terraces (Turkelboom et al., 1997; Thapa, 1997). Downhill transport of surface soil within the alley often degrades the soil in the upper part of the alleys.

The need still exists for effective and practical conservation farming systems for steeplands that reduce soil erosion, decrease the rate of tillage-induced soil movement, and minimize production costs while increasing alley crop grain and biomass yields. Ridge tillage, a conservation tillage practice that utilizes constructed soil ridges on which crops are planted and left undisturbed from harvest to planting (Laflen et al., 1978; Thapa et al., 1999a, 1999b), may be beneficial in this regard. The objective of this study was to evaluate four soil management systems for alley-cropped corn on highly erodible steepland soils in the humid tropics.

Table 1. Dates of planting, interculture, and harvest of eight successive corn crops at the Ane-i and Patrocinio sites from 1992 to 1995, Claveria, Philippines.

Year	Seeding	1st hilling	2nd hilling	Hand weeding	Harvest
1992	12 July	3 August	18 August	29 August	22 October
1993	10 May	3 June	18 June	26 June	20 August
1993	9 September	1 October	16 October	26 October	21 December
1994	8 May	1 June	16 June	23 June	18 August
1994	9 September	30 September	14 October	27 October	19 December
1995	5 January	27 January	12 February	21 February	15 April
1995	12 May	5 June	20 June	27 June	22 August
1995	22 September	14 October	29 October	4 November	10 Jan. 1996

Specifically, this paper evaluates the effects of contour barriers formed by natural grass strips and ridge tillage on corn grain yield.

MATERIALS AND METHODS

This study was conducted from 1992 through 1995 on two experimental sites at Claveria, Philippines (8°38′N, 124°55′E). The soil at the Ane-i site is a very fine, kaolinitic, isohyperthermic, Lithic Hapludox (Soil Survey Staff, 1992) with a shallow profile (<77 cm). The soil at the Patrocinio site is a very fine, kaolinitic, isohyperthermic, Rhodic Hapludox. The sites were 2 km apart with slope gradients ranging from 13 to 22%. Elevation at both sites is 500 m.

Four soil management systems (treatments) were evaluated: (i) contour moldboard plowing, the coventional practice in the region (CP); (ii) contour soil barriers formed by ridge tillage (RT); (iii) contour barriers formed by natural grass strips plus moldboard plowing (GCP); and (iv) contour barriers formed by a combination of ridge tillage and natural grass strips (GRT). Three replicates of each treatment were arranged in a randomized complete block design at each site. The 12 experimental plots in each of the two sites were 8 m wide by 38 m long (downslope). Lime (3 Mg ha^{-1}) was applied to all treatments in July 1992. No lime was added thereafter.

Dates for planting, hilling operations, weeding, and harvesting the eight successive corn crops are reported in Table 1. In this geographical region, the first corn crop typically is planted in May and harvested in August. The second corn crop is planted in September and harvested in December. This cropping cycle was followed in 1993 and 1994. With favorable rainfall late in 1994, the first crop in 1995 was planted in January and harvested in April. The remaining two crops followed the scheme for the 1993 and 1994 crops.

For the CP system, an ox-pulled, single-blade moldboard plow and harrow, in separate operations, were used to prepare the land before seeding corn. The moldboard plow was also used to make furrows for corn seeding and also to form the ridges during two ‘‘hilling up’’ operations. All tillage operations were done to a nominal depth of 20 cm along the contour. Nutrients (30 kg ha^{-1} of P and K) and Furadan-3G (2,2-dimethyl-2,3 dihydro benzo furanyl-7-methylcarbarmate) at 18 kg ha^{-1} a.i. were band-applied in the furrow at each planting. A locally adapted corn hybrid (Pioneer 3274) was manually seeded 2 cm deep in the furrows at a 25-cm spacing and covered by foot. Adjacent corn rows for all treatments were 60 cm apart. Plant population was approximately 67 000 plants ha^{-1}. Urea was surface banded (40 kg ha^{-1} N) approximately 30 cm from the corn row at 21 d after planting. A second 40 kg N ha^{-1} application was made 21 d later. The first and second hilling up operations occurred at these times.

The RT system was managed similarly to CP initially in 1992, but during the second hilling-up operation, 20-cm high ridges spaced 60 cm apart (the distance between adjacent corn rows) were constructed on the contour for the RT system using an ox-pulled, double-blade moldboard plow (ridger). These ridges were maintained permanently in the same position for the duration of the study, whereas in the CP system the ridges created in hilling up operations were destroyed during land preparation for each crop.

The GCP system was moldboard plowed on the contour. The 50 cm wide unplowed strips were left at intervals based on a 1.5-m vertical drop in elevation. Natural grasses soon invaded these unplowed strips, and distinct terraces began to form between adjacent grass strips. By September 1995, the grass strips had expanded to a width of 1 m. The 0.5 m wide uphill portion of the grass strips was plowed, thus returning the strips to their initial width. The GRT system was managed using the combination of practices described for the RT and GCP systems.

Each GCP and GRT experimental plot (Fig. 1B), then, consisted of five contour natural grass strips forming four alleyways. Each alleyway was 9 to 10 m wide depending on slope. Grass in the contour strips was cut near ground level at 45-d intervals during the corn growing season and spread uniformly on the soil surface in the alleys. Beginning in August 1994, the grass was cut at 30-d intervals to reduce its competition with the crops. Hand weeding, a customary practice in the region, was done 40 d after corn emergence in all four treatments. All vegetative material from hand weeding and the crop residues following grain harvest were returned to the alleys.

After the second crop was harvested in 1994, additional weed control was required for the RT and GRT treatments. At Patrocinio, glyphosate [isopropylamine salt of N (phosphonomethyl) glycine] at 0.9 kg a.i. ha^{-1} was sprayed after crop harvest and again 1 wk before planting the next crop. At Ane-i, hand weeding was performed 2 wk before crop harvest in lieu of the glyphosate application. These operations were in addition to the customary hand weeding described above.

Each experimental plot was subdivided into 20 compartments and numbered consecutively from 1 to 20 with the compartment at the lowest elevation on the landscape (foot slope) being assigned the number 1 (Fig. 1). Each compartment had three or four rows of corn and therefore had either three or four ridge and valley (interrow) areas. For the statistical analysis, compartments at comparable locations ineach alley (GCP and GRT) or equivalent alley locations(CP and RT) were designated as Zones I, II, III, IV, and V (Fig. 1).

Corn was harvested by compartment by cutting stalks at ground level. Weight of the shelled grain and its moisture content were determined. Corn grain yield for the whole plot was computed (80 g kg^{-1} grain moisture) based on total land area (i.e., the area occupied by the corn crop for treatments CP and RT). For treatments GCP and GRT, total land area included the cropped alleys plus the areas occupied by the grass strips.

For soil characterization, soil samples were taken from one soil pit per site, air-dried, ground to pass through a 2-mm sieve, and analyzed at the International Rice Research Institute (IRRI). Soil particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soil bulk density for each horizon was determined using intact 5 cm i.d. by 5 cm long soil cores. Total C was determined by the Walkley and Black procedure (Nelson and Sommers, 1982) and total N

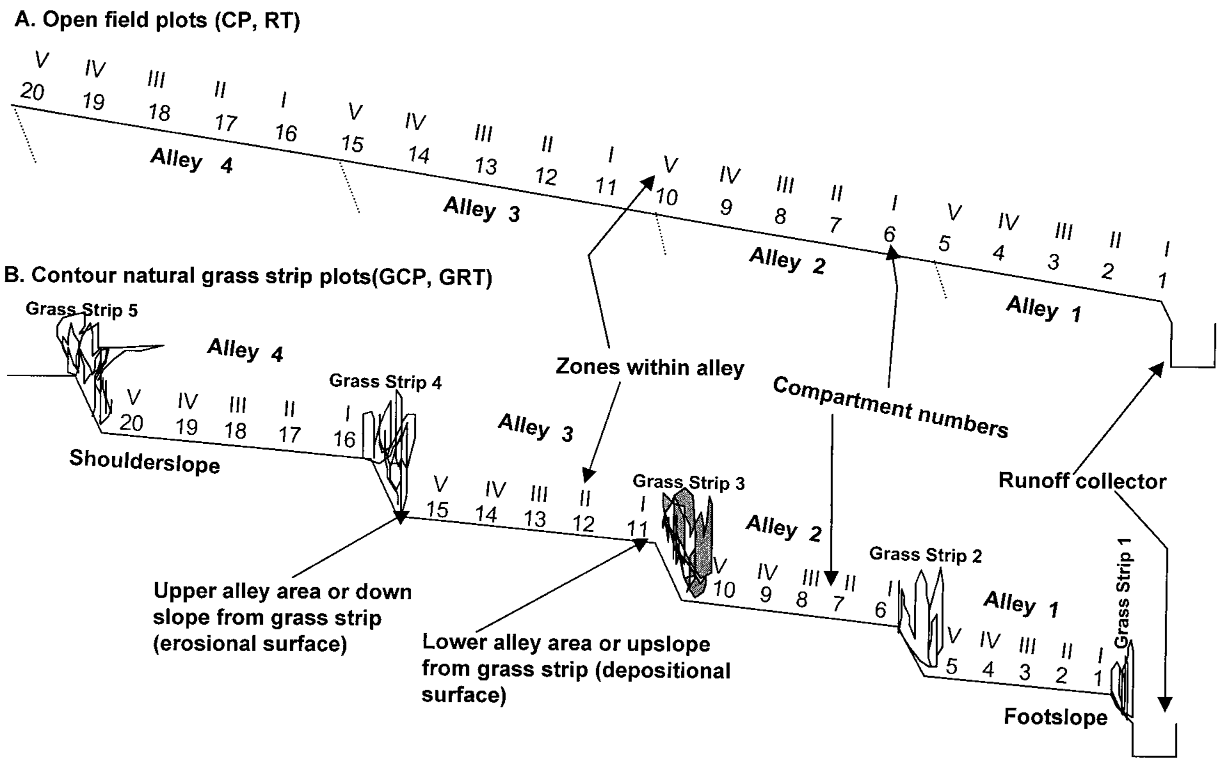

Fig. 1. Schematic diagram for (*A*) open field (contour plowing, CP, and ridge tillage, RT) and (*B*) contour natural grass strip (GCP and GRT) plots.

by Kjeldahl digestion (Olsen and Sommers, 1982). Phosphorus was extracted with the Bray-2 extractant (Olsen and Sommers, 1982). Soil exchangeable Na, K, Ca, and Mg were extracted with 1 *M* NH_4OAC at pH 7 (Thomas, 1982) and analyzed using an atomic absorption spectrometer. Aluminum was extracted with 1 *M* KCl (Barnhisel and Bertsch, 1982) and titrated with 0.1 *M* HCl. Cation exchange capacity (CEC) was calculated as the sum of Ca, K Mg, Na, and Al extracted with 1 *M* NH_4OAC at pH 7 (Soil Survey Staff, 1992). Soil pH (1:1 soil/water ratio) was measured by glass electrode (McLean, 1982). Soil physical and chemical properties for both sites are presented in Table 2.

Annual rainfall was 1561 mm in 1992, 2099 mm in 1993, 2020 mm in 1994, and 1901 mm in 1995 (Fig. 2). The greater rainfalls were due mainly to typhoons. Although typhoons did not occur at Claveria, intensive rainfall (>300 mm d^{-1}) occurred at the study site during typhoon periods. Pan evaporation at Claveria typically exceeds rainfall from January through May and rainfall exceeds pan evaporation from June through December. Claveria generally receives greater amounts of rainfall during June, July, and August, resulting in greater crop yields during this period. Mean maximum and minimum air temperatures at Claveria are 28 and 21°C, respectively.

Analyses of the corn yield data involving two sites, 4 yr, three blocks, four treatments, four alleys, five zones, and one to three crops per year as sources of variation presented a challenge. A combined factorial analysis of variance using the general linear model procedure (SAS Inst., 1988) was attempted, but the results were too complex to interpret. Combining crop yields for the entire calendar year simplified the analysis and did not result in a loss in sensitivity.

The analysis proceeded following McIntosh (1983) where blocks and sites (location) were considered as random effects, and years, treatments, alleys, and zones were considered fixed effects. In addition, the data were also analyzed separately by year, site, and site within year. Differences are reported among means for years, sites, zones, and alleys.

Table 2. Selected soil physical and chemical properties at the Ane-i and Patrocinio sites, Claveria, Phillippines, 1992.

Soil depth	Clay	Silt	Bulk density	Total C	Total N	Bray P	Exchangeable cations K	Na	Ca	Mg	Al	CEC at pH 7	Al Sat†	Soil pH
cm	%		$Mg\ m^{-3}$	$g\ kg^{-1}$		$mg\ kg^{-1}$	$cmol^+\ kg^{-1}$						%	H_2O (1:1)
Ane-i														
0–15	78	19	0.73	16.0	2.0	5.7	0.35	0.04	2.41	0.23	1.02	9.1	25.2	4.1
15–37	85	14	0.85	9.0	1.0	2.0	0.22	0.07	1.25	0.18	1.50	8.2	46.6	3.7
37–77	88	11	0.94	5.0	1.0	2.3	0.05	0.06	1.25	0.28	2.10	7.9	56.2	4.1
Patrocinio														
0–23	72	24	0.90	16.0	2.0	4.5	0.23	0.05	4.45	0.66	0.13	9.7	2.4	4.4
23–48	84	14	0.94	9.0	1.0	2.5	0.11	0.06	2.54	0.36	0.47	6.7	13.3	4.0
48–64	79	19	0.92	3.0	1.0	3.4	0.04	0.09	0.87	0.07	2.37	5.8	69.0	4.1
64–148	83	15	0.93	5.0	1.0	3.4	0.04	0.07	1.23	0.22	1.51	5.4	49.0	4.1
148–192	69	29	0.88	2.0	1.0	3.8	0.03	0.09	0.51	0.19	2.63	5.9	76.2	4.5

† Based on effective cation exchange capacity.

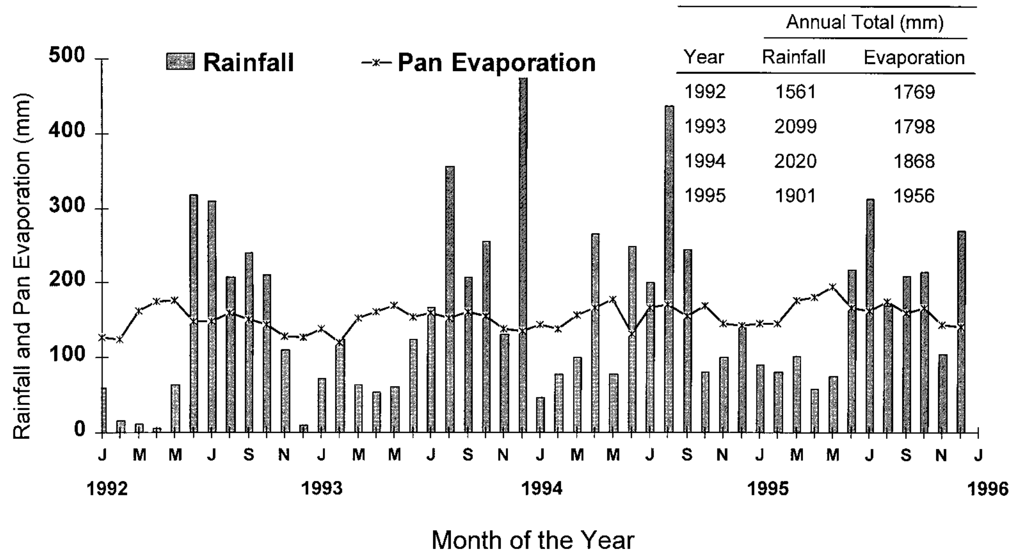

Fig. 2. Annual and monthly rainfall and pan evaporation for 1992 through 1995 at Claveria, Misamis Oriental, Philippines (adapted from IRRI, 1992–1995)

RESULTS AND DISCUSSION

Corn Grain Yield

Significant corn grain yield differences were observed for year, site, treatment, alley, zone, and for interactions of treatment with year, site, and compartment effects (Table 3). Interaction of treatment with site and year (y × s × t) indicated that yield differences due to various soil management treatments also depended on year and location. Similarly, the treatment interactions with site and alley (s × t × a) and year, alley, and compartment (y × t × a × c) indicated that grain yield response to soil management treatment varied spatially within an alley as well as temporally during the study period.

Annual corn grain yields and their means, averaged across both sites for the four soil management treatments, on a total land area basis and an alley area basis, are presented in Table 4. The RT system had little effect on grain yield until 1995 when it increased by about 0.8 Mg ha^{-1} from that for CP (total land basis). In 1995, the GRT yield was 0.71 Mg ha^{-1} larger than for GCP. Comparison of grain yields for treatments RT and GRT shows that the yield reduction due to grass strip occupancy in 1995 was 0.46 Mg ha^{-1}. Thus, yields on the cropped area basis were increased 6% in the presence of the grass strips (mean of GCP + GRT compared with CP + RT). However, this yield increase was not large enough to fully compensate for nonproduction on the land occupied by the grass strips. On the total area basis, the mean yields in 1995 for CP + RT were still 6% greater than the mean for GRT + GCP. Mean yields for the 4 yr show that the yields for RT were superior to or on par with the yields for CP in the presence or absence of the grass strips. This was true whether yields are reported on an alley basis or a total area basis. This result suggests a distinct advantage for the ridge tillage system when one considers the cost reduction observed by eliminating all primary tillage operations.

Annual corn grain yields by site on a total area basis are shown in Table 5. No differences in CP and RT yields were observed for either site in 1992 or 1993. Similar results in these years were observed for the GRT and GCP treatments. However, the RT and CP yields

Table 3. Randomized complete block analysis of variance combined across years, sites, alleys, compartments, blocks, and treatments for the corn grain yield.

Source	*df*	MSE†	DMSE
Year (y)	3	658.37**	y × s
Site (s)	1	177.41***	Block (y × s)
Treatment (t)	3	8.37*	t × s
Alley (a)	3	7.92*	a × s
Compartments (c)	4	8.02***	c × s
y × s	3	11.11**	Block (y × s)
y × t	9	2.17*	y × t × s
y × a	9	0.35 ns	y × a × s
y × c	12	0.73 ns	y × c × s
s × t	3	0.94***	pooled error
s × a	3	0.93***	pooled error
s × c	4	0.04 ns	pooled error
t × a	9	0.44 ns	t × a × s
t × c	12	0.99**	t × c × s
a × c	12	0.39 ns	a × c × s
Block (y × s)	16	1.93	
y × s × t	9	0.53***	pooled error
y × s × a	9	1.07***	pooled error
y × s × c	12	0.40**	pooled error
y × t × a	27	0.12 ns	y × t × a × s
y × t × c	36	0.15 ns	y × t × c × s
y × a × c	36	0.18*	y × a × c × s
s × t × a	9	0.49***	pooled error
s × t × c	12	0.15 ns	pooled error
x × a × c	12	0.23 ns	pooled error
t × a × c	36	0.16 ns	t × a × c × s
y × s × t × a	27	0.16 ns	pooled error
y × s × t × c	36	0.20 ns	pooled error
y × s × a × c	36	0.11 ns	pooled error
y × t × a × c	108	0.12*	y × t × a × c × s
s × t × a × c	36	0.14 ns	pooled error
y × s × t × a × c	108	0.09 ns	pooled error
Pooled error	1264	0.15	

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Effects were tested using MSE (mean square error) and DMSE (denominator mean square error) following the method of McIntosh (1983).

Table 4. Annual corn grain yield, averaged across sites, on a total land basis and an alley area basis as affected by soil management system at Claveria, Philippines, 1992 to 1995.

Soil management system†	1992	1993	1994	1995	Mean
Total land area basis					
CP	1.29b‡	8.39a	7.32a	9.97b	6.74b
RT	1.39a	8.28a	7.23a	10.76a	6.92a
GCP	1.28b	7.57b	6.73b	9.59c	6.28c
GRT	1.36ab	7.64b	6.38c	10.30b	6.42c
Alley area basis					
CP	1.29b	8.39b	7.32b	9.97c	6.74c
RT	1.39a	8.28b	7.23b	10.76b	6.92b
GCP	1.37ab	8.66a	7.70a	10.99b	7.19a
GRT	1.45a	8.72a	7.29b	11.77a	7.31a

† CP, contour moldboard plowing; RT, contour ridge tillage; GCP, contour natural grass strip plus moldboard plowing; GRT, contour natural grass strip plus ridge tillage.
‡ Means in a given column for a particular area basis followed by a common letter are not significantly different at the $P = 0.5$ level by Duncan's multiple range test.

in 1993 were noticeably greater than the yields of the GRT and GCP systems. In 1995, this trend was altered at Patrocinio, when the highest yield was for GRT (10.75 Mg ha^{-1}) compared with CP (10.01 Mg ha^{-1}) and GCP (9.86 Mg ha^{-1}). The GCP system at Ane-i produced a significantly lower yield compared with CP, RT, and GRT while yields for these latter three systems were comparable. Ridge tillage produced the highest yield in 1995 at both sites.

Corn grain yields were greater at Patrocinio than at Anei-i (Table 5), likely due to higher native soil fertility at Patrocinio. The primary reason for greater yields in 1995 is that weather conditions permitted three crops rather than two. Conversely, the lowest annual yields occurred in 1992 for only one crop. In addition, an approximately 1 mo long rainless period beginning after the second hilling up operation in August 1992 severely stressed the crop.

In 1992 and 1993, the greater grain yields for CP on a total land area basis (Table 5) were related to more land area planted to corn compared with the GRT and GCP treatments. Other factors likely contributing to the yield reduction in GCP and GRT are shading and competition for water and nutrients by the grass. Because contour natural grass barriers reduce soil loss, the land area occupied by the grass strips could be considered conservation land rather than crop land. In this case, one can compute grain yield on a cropped land or alley area basis. Mean corn grain yield based on the cropped alley area was always highest for GRT followed by the GCP, RT, and CP systems.

The lowest 1995 grain yield occurred for GCP at Ane-i (Table 5) and was due mainly to moldboard plowing 20 cm deep, which exposed and mixed Al-rich subsoil with the surface soil (data not shown). Agus et al. (1997) reported a subsoil pH of 3.6 at a site (Rhodic Hapludox) near this experimental area when analyzed by the KCl method. Similar soil pH values were observed in this study. Mixing highly acidic subsoil into the topsoil increases soil acidity of the surface soil which detrimentally affects corn growth, especially in the upper alley. The low soil pH may have other unknown effects on nutrient availability and chemical toxicities. Differences in soil acidity within alleys have not been considered as a possible contributing factor for yield decline near the contour hedgerow strips, especially when the indigenous farmers' plowing method is practiced. However, upon observation of reddish subsurface soil being mixed into the soil surface in the upper alley area of GCP (near the downslope of grass strips), it is plausible that low pH, higher Al saturation, and Mn toxicity might contribute to the differences in yield.

In 1995, significantly greater RT and GRT yields on a total land area basis compared with previous years were due to minimal mixing and redistribution of Al-rich subsurface horizon material into the surface soil. The contour barriers formed by grass strips and soil ridges in RT and GRT also served to reduce runoff and soil sediment and nutrient loss. As a result, the N, P, and K nutrients not used by the crop were better conserved within the RT and GRT systems compared with the CP

Table 5. Annual corn grain yields by site on a total land area basis as affected by soil management system at Claveria, Philippines, 1992 to 1995.

	Year			
Soil management system†	1992	1993	1994	1995
	Mg ha^{-1}			
Ane-i				
CP	0.99b‡	7.39a	6.73a	9.92a
RT	1.10ab	7.40a	6.25b	10.09a
GCP	1.08ab	6.71b	6.07b	9.32b
GRT	1.17a	6.68b	5.50c	9.85a
Patrocinio				
CP	1.59ab	9.39a	7.91b	10.01c
RT	1.69a	9.16a	8.21a	11.44a
GCP	1.48b	8.43b	7.39c	9.86c
GRT	1.54b	8.58b	7.26c	10.75b

† CP, contour moldboard plowing; RT, contour ridge tillage; GCP, contour natural grass strip plus moldboard plowing; GRT, contour natural grass strip plus ridge tillage.
‡ Means in a given column for a particular site followed by a common letter are not significantly different at the $P = 0.05$ level by Duncan's multiple range test.

Table 6. Mean annual corn grain yield averaged across sites on a total area basis and an alley area basis for five zones within each soil management system on sloping land.

	Soil management system‡			
Zone†	CP	RT	GCP	GRT
	Mg ha^{-1}			
Total area basis				
I	6.79 (3.5)§	6.88 (3.5)	6.37 (3.3)	6.53 (3.5)
II	6.91 (3.5)	7.02 (3.6)	6.63 (3.5)	6.50 (3.3)
III	6.83 (3.5)	6.97 (3.7)	6.56 (3.4)	6.67 (3.6)
IV	6.69 (3.5)	6.93 (3.6)	6.57 (3.5)	6.65 (3.7)
V	6.49 (3.5)	6.77 (3.8)	5.33 (2.8)	5.73 (3.3)
Alley area basis				
I	6.79 (3.5)	6.88 (3.5)	7.27 (3.8)	7.44 (4.1)
II	6.91 (3.5)	7.02 (3.6)	7.56 (4.0)	7.40 (3.8)
III	6.83 (3.5)	6.97 (3.7)	7.48 (3.9)	7.60 (4.2)
IV	6.69 (3.5)	6.93 (3.6)	7.50 (4.0)	7.58 (4.2)
V	6.49 (3.5)	6.77 (3.8)	6.10 (3.3)	6.53 (3.8)

† I is the lower portion of the alley, V is the upper portion of the alley; II, III, and IV are between Zone I and V (see Fig. 1 for detail).
‡ CP, contour moldboard plowing; RT, contour ridge tillage; GCP, contour natural grass strip plus moldboard plowing; GRT, contour natural grass strip plus ridge tillage.
§ Standard deviation in parentheses.

system (Thapa, 1997). We must keep in mind that the greater 1995 yields for RT and GRT systems occurred in well fertilized and limed fields. Under current farm management in the Claveria region, less fertilizer is applied than we used in this study. For land receiving small fertilizer applications, we would expect to find a larger yield difference between the ridge tilled and moldboard plowed tillage systems.

Landscape Effects on Corn Grain Yield

Zone V, in the upper alley, but immediately downslope from the grass strips in GCP and GRT (see Fig. 1B), had a significantly lower yield compared with the other four zones (Table 6). The yield reported for each zone is the average of 24 observations (2 sites × 3 reps × 4 alleys). Mean annual yield differences among zones for CP and RT were not anticipated, but the yields of Zone V for GCP and GRT were about 1 Mg ha^{-1} yr^{-1} less than the other four zones. For Zone V, the approximately 0.4 Mg ha^{-1} yr^{-1} greater grain yield for GRT compared with GCP may be related to ridge tillage slowing down the rate of soil transport downslope. This observation supports our hypothesis in treatment design that RT would be beneficial in reducing soil degradation in the upper alley. However, it did not eliminate these effects within the time period of the experiment. The yield difference between Zones I and V, however, was not as large as those reported by Solera (1993) and Garrity (1996). These investigators reported yield reductions as large as 50% in Zone V of an alley with tree legume barriers. Natural grasses, due to their shorter height, may be less competitive to crops than legume tree or hedgerow species.

Grain yield averaged across sites for each treatment for 1993, 1994, and 1995, as a function of compartment, is shown in Fig. 3. Compartment corn grain yields generally decreased from the foot slope to the shoulder slope. The patterns in grain yield vs. compartment in 1993 and 1994 were comparable for CP and RT (Fig. 3A, 3C) and for GCP and GRT (Fig. 3B, 3D). Yields for the latter two treatments were always greater than the former two except for Compartments 5, 10, 15, and 20 (Zone V) that are immediately downslope from the grass strips. Only in 1995 was this pattern different, when the trend was for RT and GRT to have greater yields than CP and GCP in the upper portion of the landscape, but similar yields in the lower portion of the landscape (Fig. 3E). The strong trend for lower yields in the compartment just downslope of the grass strip (Zone V) observed in 1992 (not shown), 1993, and 1994 was not seen in 1995. It appears that in 1995 the scouring effect was in the process of being ameliorated, particularly in the GRT treatment. This issue needs further research.

The low grain yields near Compartments 5, 10, 15, and 20 (all Zone V) of GCP and GRT before 1994 are

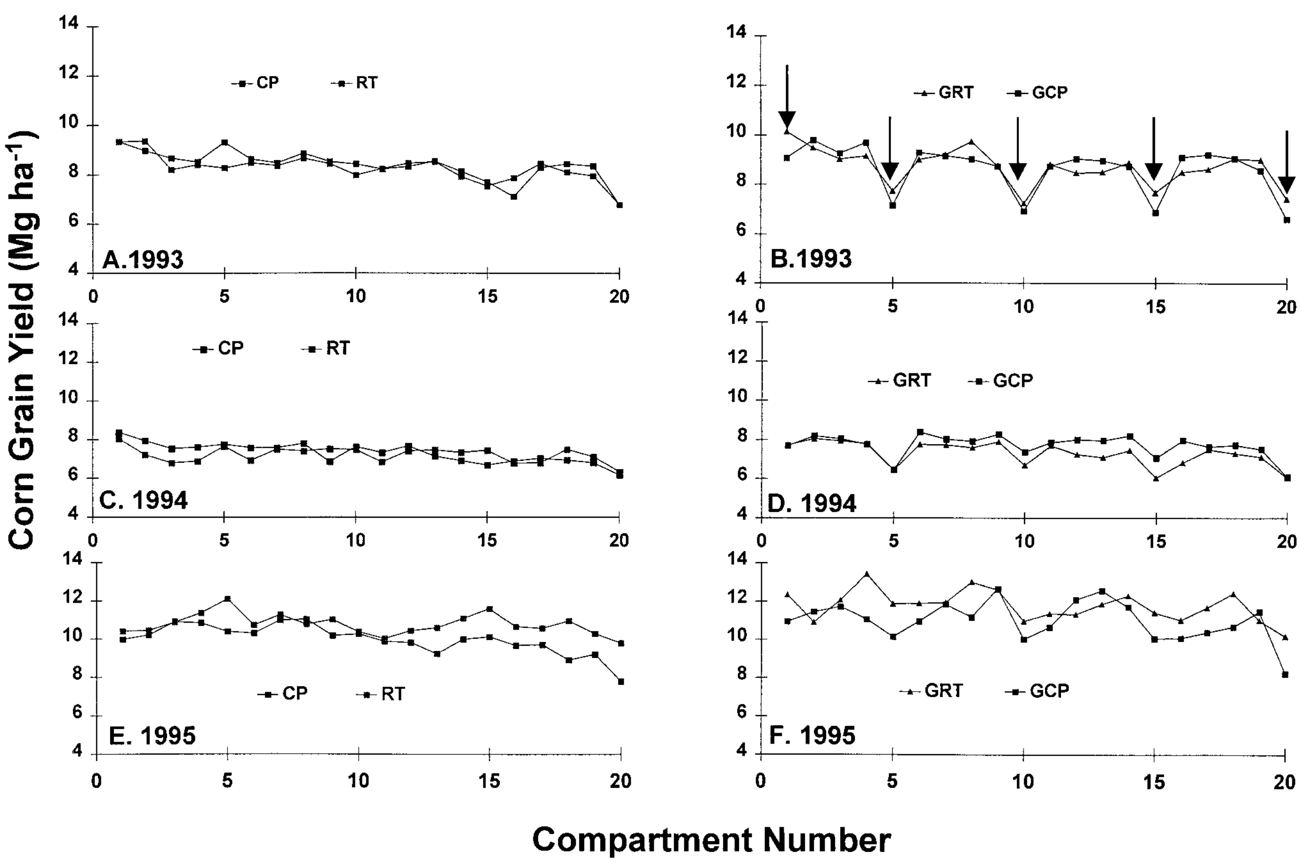

Fig. 3. Mean annual corn grain yield by compartment averaged across sites as affected by four management systems at Claveria, Phillippines from 1993 to 1995. (CP, contour moldboard plowing; RT, contour ridge tillage; GCP, contour natural grass strip plus moldboard plowing; GRT, contour natural grass strip plus ridge tillage). Arrows indicate position of grass strips.

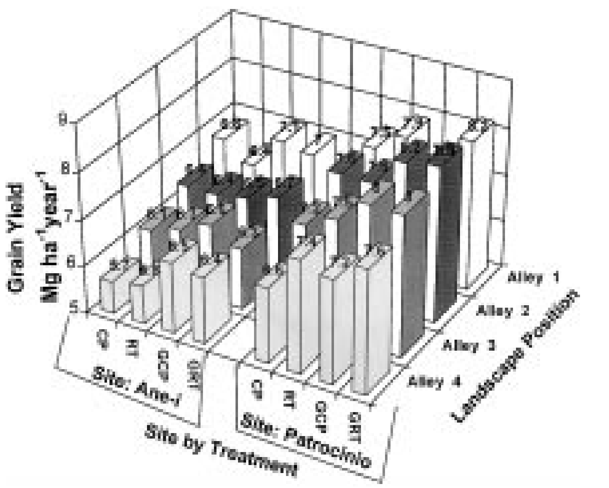

Fig. 4. Alley area basis mean corn grain yield for eight crops at Claveria, Philippines. Alley 1 is in the foot slope and Alley 4 is in the shoulder slope. (CP, contour moldboard plowing; RT, contour ridge tillage; GCP, contour natural grass strip plus moldboard plowing; GRT, contour natural grass strip plus ridge tillage).

attributed to competition between the grass in the strips and the crops for nutrients, water, and sunlight. Corn plants adjacent to the grass strips at the Ane-i site appeared chlorotic. Shading of the adjoining crop rows by Guinea grass (*Panicum maximum*) and Rotboellia (*Rottboellia cochinchinensis*), two grasses common in the contour barrier strips that grew as tall as 2 m, was evident. The excessive height of grass in the contour barrier strips was due to 45-d intervals between consecutive prunings, an interval too long in this tropical environment.

In 1994 and 1995 the yield depression in Zone V (downslope from the grass strips) nearly disappeared. This response coincides with the adoption of 30-d intervals between pruning the grass strips and reducing the width of the grass strips from 1 to 0.5 m. As a result of 30-d pruning frequency, grasses never exceeded a height of 0.5 m. In addition to reducing the width of the barrier strips, returning a portion of the grass strip to the alley area added nutrients along the upper alley area.

The effect of alley location on grain yield for eight crops was observed for each treatment at each site (Fig. 4). The overall trend is for yield to decrease from Alley 1, at the footslope position to Alley 4, in the shoulder slope. Soil moisture in the footslope position for this soil is usually higher than further upslope (Agus et al., 1997). The footslope is also typically the site of soil accumulation and plant nutrient deposition. The shoulder slope is the region where plant-available water and rooting volume are lower and plant nutrients are less plentiful. Alley 4 (shoulder slope) of CP produced the lowest yield at both the Ane-i and Patrocinio sites.

Modeling Crop Yield for Sloping Land

Landscape positions on sloping land represent unique combinations of soil physical, chemical, and biological properties. As a first approach to modeling crop yields in

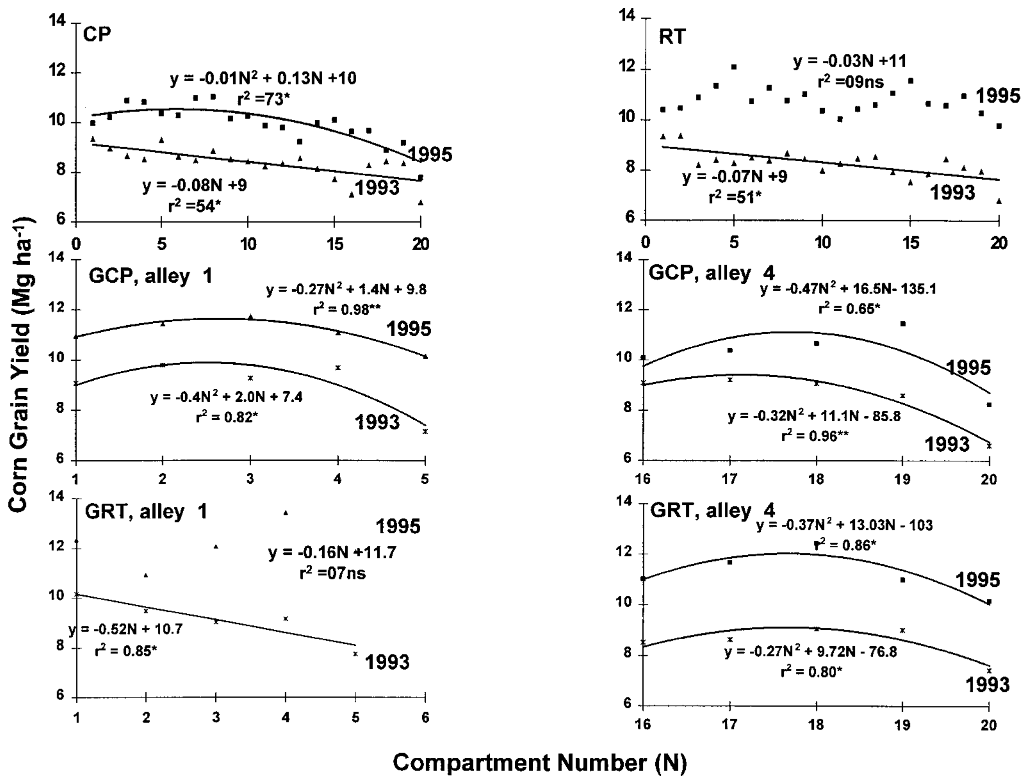

Fig. 5. Mean corn grain yield averaged across sites for each soil management system in 1993 and 1995 as a function of landscape position (compartment). Alley 1 is in the foot slope and Alley 4 is in the shoulder slope position. For GCP and GRT, Compartments 1 and 16 are in the lower part of the alleys and Compartments 5 and 20 are in the upper part of alleys. * and ** indicate significance at the $P = 0.05$ and 0.01 levels, respectively; ns = not significant.

alley cropping experiments, van Noordwijk and Garrity (1995) used a parabola to describe relative crop yields across the alleys. In our study, the grain yield response model for each treatment for each year was calculated; only the response curves for 1993 and 1995 are shown (Fig. 5). In 1993 the models for CP and RT were linear. The yield responses in 1995 were curvilinear, but not parabolic. Treatments GCP and GRT are each composed of four alley-grass barrier strip repeating units giving rise to a series of four microlandscapes, each with small-scale erosional and depositional surfaces. Quadratic yield functions for GCP were found for all four alleys in 1993 and 1995. Data for Alleys 1 and 4 are shown in Fig. 5. The parabolic yield function proposed by Garrity (1996) was attributed to hedge–crop interspecies competition for growth resources such as sunlight, water, and plant nutrients. Curvilinear yield functions for this study are attributed to competition for resources by the native grasses in addition to differences in soil properties as a result of deeper soils at the lower alley position.

CONCLUSIONS

After eight successive corn crops on fertilized and limed soil, the contour ridge tillage system, either alone or in combination with contour natural grass barrier strips, had about 1 Mg ha^{-1} greater corn grain yields when compared with the contour moldboard plowing (alone or in combination with grass barrier strips) system. This greater yield for the ridge tillage system was obtained with lower investment for tillage costs compared with the intensive moldboard plow system. The superiority of the ridge tillage system occurred for well-fertilized, researcher-managed field trials. Under the farmers' current farming system, which receives less fertilizer, the yield advantage of ridge tillage likely would be more pronounced compared with the moldboard plow system. The lower yield in 1995 for the combination of contour ridge tillage and natural grass barrier strips compared with ridge tillage alone reflects the yield reduction due to the grass strip occupancy.

The reduction of area planted to crops due to contour grass strip occupancy represents an important constraint for farmers with small land holdings in the region. Yet the advantages of natural grass strips are their simplicity of installation, absence of initial input costs, and reduction in soil erosion. Terraces gradually form in the alleyways, thus stabilizing the soil. If desired, a farmer could diversify use of the stabilized terrace by planting various crops including tree or perennial crops, according to changing management objectives.

REFERENCES

Agus, F., D.K. Cassel, and D.P. Garrity. 1997. Soil-water and soil physical properties under contour hedgerow systems on sloping Oxisols. Soil Tillage Res. 40:185–199.

Barnhisel, R., and P.M. Bertsch. 1982. Aluminum. p. 275–300. *In* Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Buck, M.G. 1986. Concepts of resource sharing in agroforestry systems. Agroforestry Syst. 4:191–203.

Garrity, D.P. 1993. Sustainable land-use systems for sloping uplands in southeast Asia. p. 44–66. *In* J. Ragland and R. Lal (ed.) Technologies for sustainable agriculture in the tropics. ASA Spec. Publ. 56. ASA, Madison,WI.

Garrity, D.P. 1996. Tree-soil-crop interactions on slopes. p. 299–318. *In* C.K. Ong and P. Huxley (ed.) Tree–crop interactions, a physiological approach. CAB International, Wallingford, UK.

Garrity, D.P., and A.R. Mercado. 1994. Nitrogen fixation capacity in the component species of contour hedgerows: How important? Agroforestry Syst. 27:241–258.

Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383–411. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

IRRI. 1992 to 1995. Compilation of weather data for 1993, 1994, and 1995. IRRI Climate Unit, Agron., Plant Physiol., and Agroecology Div., Los Banos, Laguna, Philippines.

Kang, B.T., and G.F. Wilson. 1987. The development of alley cropping as a promising technology. p. 227–243. *In* H.A. Steppler and P.K.R. Nair (ed.) Agroforestry: A decade of development, Int. Counc. for Res. Agroforestry, Nairobi, Kenya.

Lal, R. 1990. Soil erosion in the tropics. McGraw-Hill, New York.

Laflen, J.M., J.L. Baker, R.O. Hartwig, W.F. Buchele, and H.P. Johnson. 1978. Soil and water loss from conservation tillage systems. Trans. ASAE 24:605–690.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199–224. *In* Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. p. 539–579. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403–430. *In* Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Palm, C.A. 1995. Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry Syst. 30:105–124.

Sanchez, P.A. 1995. Science in agroforestry. Agroforestry Syst. 30:5–55.

SAS Institute. 1988. SAS/STAT users' guide. Release 6.03 ed. SAS Inst., Cary, NC.

Soil Survey Staff. 1992. Keys to soil taxonomy. 5th ed. SMSS Tech. Monogr. 19. Pocahontas Press, Blacksburg, VA.

Solera, C. 1993. Determination of competition between hedgerow and alley species in a contour hedgerow inter-cropping system. Ph.D. diss. Univ. of the Philippines, Los Banos, Laguna, Philippines.

Thapa, B.B. 1991. Evaluation of infiltration, surface runoff, and soil losses at various levels of rainfall in relation to surface cover, tillage, and soil management practices. M.S. thesis. Univ. of the Philippines, Los Banos, Laguna, Philippines.

Thapa, B.B. 1997. Contour ridge tillage and natural grass barrier strip effects on soil erosion, soil fertility, and corn production on sloping Oxisols in the humid tropics. Ph.D. diss. North Carolina State Univ. Diss. Abstr. AAI9813808.

Thapa, B.B., D.K. Cassel, and D.P. Garrity. 1999a. Ridge tillage and contour natural grass barrier strips reduce tillage erosion. Soil Tillage Res. 51:341–356.

Thapa, B.B., D.K. Cassel, and D.P. Garrity. 1999b. Assessment of tillage erosion rates on steepland Oxisols in the humid tropics using granite rocks. Soil Tillage Res. 51:233–243.

Thomas, G.W. 1982. Exchangeable cations. p. 159–165. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Turkelboom, F., J. Poesen, I. Ohler, K. Van Keer, S. Ongprasert, and K. Vlassak. 1997. Assessment of tillage erosion rates on steep slopes in northern Thailand. Catena 199:1–16.

van Noordwijk, M., and D.P. Garrity. 1995. Nutrient use in agroforestry systems. *In* Proc. of the 24th Int. Colloquium of the International Potash Inst., Basel, Switzerland.

Young, A. 1989. Agroforestry for soil conservation. CAB Int., Wallingford, UK.