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Soil-water and soil physical properties under contour hedgerow systems on sloping oxisols

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Abstract

Hedgerows planted along the contour on steep lands in the humid tropics reduce soil erosion and build terraces over time. The objectives of this study in two Hapludoxes in the Philippines were to evaluate changes after 4 years in soil properties and soil water relations on transects perpendicular to the cropped alleys between four grass and tree hedgerow systems and a control. Hedgerow plants included *Gliricidia sepium*, *Paspalum conjugatum*, and *Penisetum purpureum*. Soil properties evaluated as a function of position in the alley (upper, middle, or lower elevation in an alley) included bulk density, mechanical impedance, soil water transmissivity, water retention, soil water pressure, and soil water content. In general, soil properties were not affected by hedgerow system, but were affected by position in the alley. Nearness to the hedgerow, but not hedgerow species, affected soil water distribution ($P = 0.05$). Plant available water at the 10–15 cm depth was $0.16\,m^3\,m^{-3}$, $0.13\,m^3\,m^{-3}$, and $0.08\,m^3\,m^{-3}$ for the lower, middle, and upper alley position, respectively. Water transmissivity decreased from $0.49\,mm\,s^{-1}$ in the lower alley to $0.12\,mm\,s^{-1}$ in the upper alley. The lower soil water contents and soil water pressures in and near the hedgerows confirmed competition for water between the hedgerow species and the food crop in the alley, a condition that is expected to suppress food crop production.

Keywords: Alley cropping; Hedgerows; Soil physical properties; Soil water retention; Soil water transmissivity

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1. Introduction

Intensive cereal-based farming systems on sloping, acid, infertile soils are replacing shifting cultivation in many areas (Garrity et al., 1993). Without adequate soil and water conservation measures, these intensive farming systems are not sustainable. Agroforestry approaches to control soil erosion and concomitant productivity decline are being evaluated for a range of marginal, sloping land environments (e.g. Kang et al., 1990; Lal, 1991; Mellink et al., 1991). The use of narrow vegetative strips of trees, shrubs or grasses planted on the contour, often called 'contour hedgerows', is one experimental management practice with potential to reduce soil erosion on sloping lands in the humid tropics (Garrity, 1993). Food crops are planted in the alleys, that is, the areas between the hedgerows. Each hedgerow reduces soil erosion by infiltrating surface water runoff, and filtering aggregates and soil particles suspended in runoff water. Soil material detached from the upper part of an alley moves only a short distance and is then deposited in the lower part of the alley. This process, along with tillage-induced soil movement, gradually reduces the slope in the alley and develops a downslope thickening of the Ap horizon.

Lal (1991) stated that the impact of hedgerow systems should be verified in specific geographical areas before they are recommended to farmers. Installation of hedgerows reduces the area for food crop production in the alleys and may reduce food crop yields. It is of agronomic importance to know why yields increase or decrease in response to specific management practices. The soil water regime under contour hedgerow systems in sloping Hapludoxes is not understood. Nor is there adequate documentation of expected changes in soil physical properties that occur in response to soil movement from the upper to the lower part of an alley.

The objectives of this study were: (1) to evaluate temporal and spatial changes in soil water content and pressure head under several control hedgerow systems and (2) to document the soil physical properties in several 4-year-old contour hedgerow systems. The effects of these hedgerow systems on food crop yields are discussed in detail elsewhere (Agus et al., 1997).

2. Methods

This study was conducted from December 1991 to November 1992 at two sites where contour hedgerows were planted in June 1988. The two upland sites, designated Compact and Cabacungan, were in farmers' fields in Claveria, Misamis Oriental Province, Mindanao, 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. The soil at the Cabacungan site (200 m elevation and 1200 mm mean annual rainfall) is a very fine, kaolinitic, isohyperthermic Rhodic Hapludox. Selected soil properties are given in Table 1 (Subagjo et al., 1993).

The following four contour hedgerows systems were established in June 1988: (1) double rows of the leguminous tree *Gliricidia sepium* (G); (2) a single row of *G. sepium* and single row of the native short-statured bahia grass *Paspalum conjugatum* (GPas);

Table 1
Selected soil properties at the Compact and Cabacungan sites (after Subagjo et al. (1993))

Soil depth (m)	Horizon	Cation exchange capacity cmol(+)kg^{-1}	Al saturation (%)	pH(1:1) w/v in 1N KCl	Organic carbon (g kg^{-1})	Clay (%)	Silt (%)	Bulk density (Mg m^{-3})
Compact								
0–0.14	A	7.17	33	3.8	13	75	23	1.09
0.14–0.31	AB	6.66	70	3.6	5	71	27	1.05
0.31–0.59	Bo1	6.37	89	3.6	4	72	26	1.00
0.59–0.85	Bo2	6.35	94	3.5	4	74	24	0.95
0.85–1.11	Bo3	6.49	93	3.4	4	70	28	0.90
Cabacungan								
0–0.06	A	8.19	22	4.1	18	82	16	0.91
0.06–0.28	AB	5.68	63	3.9	7	88	10	1.04
0.28–0.54	Bo1	5.22	62	3.9	6	89	10	1.09
0.54–0.83	Bo2	5.42	67	3.9	4	88	11	1.08
0.83–1.16	Bo3	5.84	72	3.8	4	50	49	1.03

(3) a single row of *G. sepium* and a row of napier, an exotic fast-growing fodder grass (*Penisetum purpureum*) (Gpen); (4) double rows of *Penisetum purpureum* (Pen). In addition, there was a fifth treatment composed of an open field conventionally farmed area with cultivation on the contour, but without hedgerows. There were two replications of each hedgerow treatment at each site, for a total of four replications across sites. Each hedgerow plot had five hedgerows and four alleys (Fig. 1(A)). The width of each main plot along the contour was 15 m and its length downslope ranged from 18 to 22 m. The slopes were 22–30%. Average hedgerow width was 0.8 m and average alley width was 4.5 m. The distance between the centers of adjacent hedgerows was based upon a 1 m change in elevation.

From hedgerow establishment until this study began in June 1991, two rice (*Oryza sativa* L.) and two maize (*Zea mays* L.) crops were grown and harvested from the alleys. In the 1991 wet season (May–September) rice (cv. 'IR-30716-B-0-1-B-1-1-2') and maize (cv. 'Pioneer 3274') were planted on 13 May on alternate alleys. The planting dates for the 1991 dry season (October–April) maize were 10 October and 29 October, for the 1992 wet season rice, 1 June and 2 June, and for the 1992 dry season maize, 26 October and 2 November, for the Compact and Cabacungan sites, respectively. The control (C) treatment and the alleys of all hedgerow treatments were plowed twice with an oxen-pulled moldboard plow and harrowed once with an oxen-pulled wooden harrow before planting each crop. Each crop received 20 kg ha^{-1} P as triple superphosphate, 20 kg ha^{-1} K as KCl, and 60 kg ha^{-1} N from urea. The rates of fertilizer and lime applications for hedgerow treatments were based on the cropped area; for the control, it was based on the entire plot area. The pruned biomass of *Gliricidia* was uniformly spread on the alleyway as mulch. *Paspalum* was not pruned because it attained a maximum height of only 40 cm. *Penisetum* clippings were removed from the plots for livestock feed, a practice common in this region. Crop residue from each food crop remained on the plot.

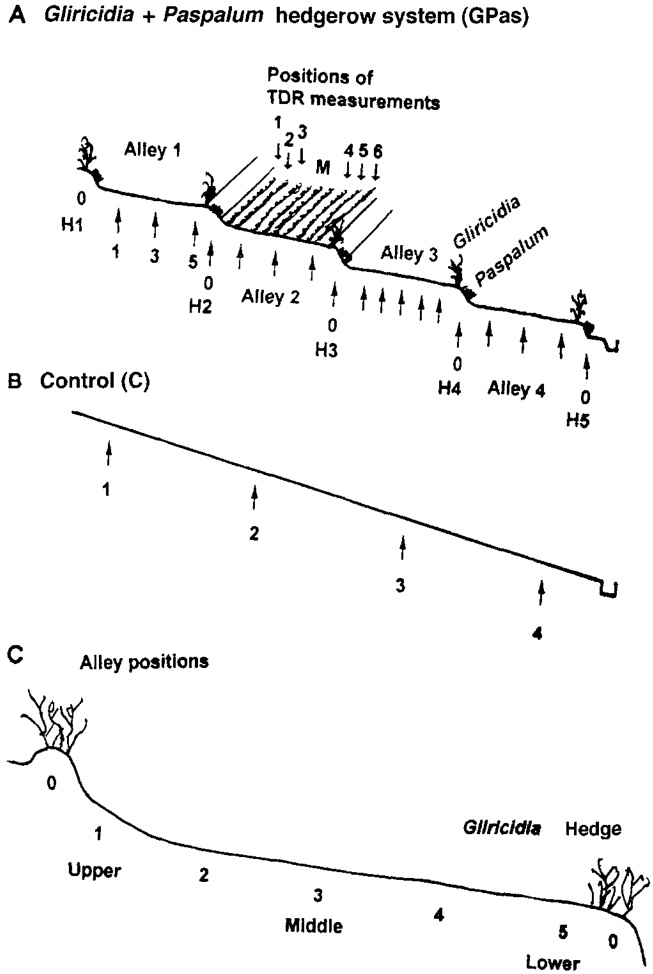

Fig. 1. Cross-sectional representation of (A) the *Gliricidia* + *Paspalum* hedgerow system (GPas) showing tensiometer and neutron access tube placement (indicated by upward pointing arrows) and TDR measurement positions (indicated by downward pointing arrows), (B) sampling points on control treatment, and (C) alley position designations in an alley.

2.1. Thickness of Ap horizon

Four years after hedgerow establishment a trench 40 cm deep and 20 cm wide, perpendicular to the hedgerow, was dug across the alleys of several plots. The lower boundary of the Ap horizon was determined based on Munsell soil color.

2.2. Soil bulk density

Bulk density was measured in January 1992 using cores of 50 mm internal diameter (i.d.) by 50 mm length collected from the 50–100 mm soil depth at the hedgerow; at the upper, middle, and lower positions in the alleys (Fig. 1(C)); and at three equally spaced positions of Treatment C (see Fig. 1(B)). For the hedgerow treatments (Fig. 1(A) and Fig. 1(C)), Position 0 is in the hedgerow and Positions 1–5 run from high to low elevations within an alley. Positions 1, 3, and 5 are referred to as the upper, middle, and lower positions, respectively. Subsampling for each position was on three transects 2 m apart.

2.3. Mechanical impedance

Mechanical impedance (MI) to a depth of 60 cm was measured with a DELMI® recording penetrometer at the Compact site in October 1991 before tillage for the second crop. Maize was the previous crop. Mechanical impedance for Treatments G, GPas, GPen, and Pen was measured at the upper, middle, and lower positions in the second alley from the top of the slope (Fig. 1); MI for the control was measured at four equally spaced positions along the slope. Plots were subsampled for water content three times on transects spaced 2 m apart. The soil water content was at field capacity for all MI measurements. The maximum MI value within each depth increment was analyzed by PROC MEANS (SAS Institute, Inc., 1988).

2.4. Soil water

Soil water transmissivity, an estimate of in situ saturated hydraulic conductivity, was measured using single ring infiltrometers (Van Es et al., 1991). The infiltrometers were 20 cm in diameter and 25 cm high, and were driven 12 cm into the soil. After covering the soil surface inside the ring with cheesecloth, a constant water head of 24 mm height was maintained. The NOINT option in PROC REG (SAS Institute, Inc., 1988) generated regression equations to estimate soil water transmissivity. The effects of treatment and position on soil water transmissivity were analyzed using analysis of variance. The means were compared using the *t*-test.

Soil water retention curves were developed using soil cores of 50 mm i.d. by 50 mm length taken at the 100–200 mm depth for the upper, middle, and lower alley positions of the Pen treatment at the Compact and Cabacungan sites. The soil cores were saturated overnight, placed in a pressure apparatus (Klute, 1986), and desorbed at soil water pressures of -30, -100, and -1500 kPa.

Soil water pressure was measured in 1991 using tensiometers connected to mercury manometers. Tensiometers were on transects perpendicular to the hedgerows. Installation was completed 3 weeks after planting rice at Compact and 2 weeks after planting maize at Cabacungan. Owing to limited resources, tensiometers were installed only in Treatments C and GPas. Three tensiometers (15 cm, 30 cm, and 45 cm depths) were installed at Positions 1–5 (Fig. 1(C)). For Treatment C, tensiometers were installed at four equally spaced positions along the plot (Fig. 1(B)). Soil water pressure head was read twice weekly.

Soil water content was measured periodically using a time domain reflectometer (TDR) constructed from a Tektronix 1502C cable tester (Tektronix, Wilsonville, OR) (Cassel et al., 1994). TDR measurements for Treatment C were taken at six equally spaced positions along the slope. Measurements for the hedgerow treatments were taken at several positions: in each of the first three rows, the middle row, and in each of the

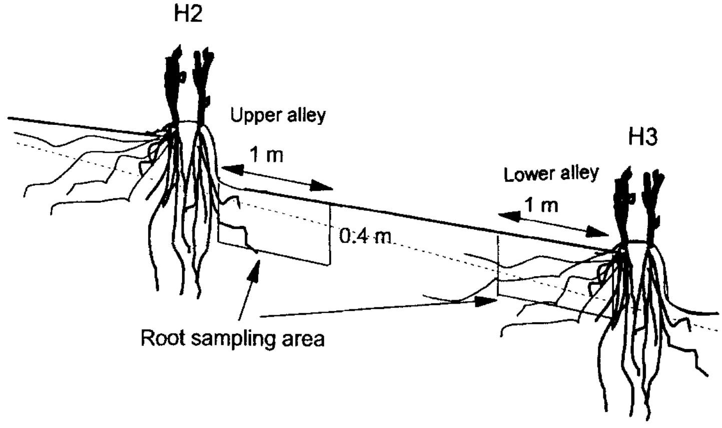

Fig. 2. Schematic representation of hedgerow crop root distribution on a *Gliricidia* hedgerow plot showing hedgerow crop root sampling positions.

last three rows of Alley 2, and in the hedgerow (Position H3) at 30 and 60 cm from the edge of the second alley (Fig. 1). The measurements were taken on three transects, each 1 m apart, at the 0–15 cm and 0–30 cm depths.

2.5. Hedgerow crop root length density

Root length density of the hedgerow crops was measured in January 1992, 1 week after maize harvest. Two trenches of 40 cm depth, 20 cm width and 100 cm length were dug perpendicular to the slope for each hedgerow treatment at each site. One trench extended downslope from the edge of Position H2, and the second extended upslope from the edge of Position H3 (Fig. 2). The trench was dug by successive excavation of soil blocks with dimensions of 20 cm × 20 cm × 10 cm depth. Roots of the hedgerow crop were separated from each soil sample. The length of roots of 0.1–5 mm diameter in each soil sample was determined by a Comair root length scanner (Commonwealth Aircraft Corp. Limited, Melbourne, Australia).

3. Results and discussion

3.1. Ap horizon thickness

Soil movement from the higher to the lower elevation within the alleys developed a gradient in Ap horizon thickness. Thickness ranged from 20–32 cm at the hedgerow and lower alley position to 5–15 cm at the upper alley position. Ap horizon thickness for Treatment C, which ranged from 6 to 15 cm at Cabacungan and from 10 to 20 cm at Compact, was not significantly different as a function of distance along the slope.

3.2. Soil bulk density

Bulk density at the 50–100 mm depth in January 1992, averaged across positions and sites for each treatment, was less than 1.0 Mg m^{-3} (Table 2). Soil water content at the

Table 2
Effect of contour hedgerow systems on soil bulk density at the 50–100 mm soil depth in January 1992 averaged across positions and sites

Treatment	Number of samples	Bulk density ($Mg\,m^{-3}$)	
		Mean	SD
Control (C)	36	0.963 [a]	0.098
Gliricidia (G)	48	0.930 [b]	0.064
Gliricidia–Paspalum (GPas)	48	0.947 [ab]	0.080
Gliricidia–Penisetum (GPen)	48	0.927 [b]	0.067
Penisetum (Pen)	48	0.965 [a]	0.088

Means in the same column followed by the same superscript letter are not significantly different using Fisher's protected least significant difference (LSD) at $P = 0.05$.

time of bulk density sampling was affected by hedgerow treatment but differences were less than 0.01 $m^3\,m^{-3}$ (data not shown). It is doubtful if these small differences would affect plant growth. However, within the alleys of the hedgerow treatments, water content was greater ($P = 0.05$) for the upper position compared with the other positions (Table 3). Greater water content in the upper alley position probably is due to either a slightly greater clay content or less water uptake owing to scanty root density at this position (to be discussed later). Despite statistically significant differences among treatments, the differences in bulk density among alley positions are probably of little agronomic importance. In a coarse-textured Oxic Paleustalf in Nigeria, Hulugale and Kang (1990) found bulk density to be greater on control plots compared with hedgerows plots. They attributed the difference to the addition of the pruning materials from hedgerows. Coarse-textured soils are usually more susceptible to compaction than are the well-aggregated fine-textured soils on which our work was done.

3.3. Mechanical impedance

Mean MI at field capacity was less than 2500 kPa throughout the entire 0–60 cm depth (data not shown). This level of MI, and the gradual change of MI observed with depth, indicates that the soil had no compacted layers to impede root growth. Soil MI

Table 3
Effect of alley position on bulk density and volumetric soil water content at the 50–100 mm soil depth in January 1992

Position	Bulk density ($Mg\,m^{-3}$)		Water content ($m^3\,m^{-3}$)	
	Mean	SD	Mean	SD
Hedgerow	0.916 [c]	0.058	0.256 [b]	0.025
Upper alley	0.958 [ab]	0.081	0.296 [a]	0.046
Middle alley	0.934 [bc]	0.083	0.271 [b]	0.047
Lower alley	0.969 [a]	0.084	0.255 [b]	0.036

Each value is the mean of 48 observations and is the average of four hedgerow treatments at both sites. Means in one column followed by the same superscript letter are not significantly different using Fisher's protected LSD at $P = 0.05$.

Table 4
Soil water transmissivity for the control and four positions in the alleyways, averaged across hedgerow treatments

Treatment	Position	Number of replications	Transmissivity (mm s^{-1})
Control	Mean	12	0.19
Hedgerow	Hedgerow	16	0.49 [a]
	Upper	16	0.12 [c]
	Middle	16	0.21 [bc]
	Lower	16	0.30 [b]
	Mean	64	0.28

Means within a given column followed by the same superscript letter are not significantly different using Fisher's protected LSD at $P = 0.05$.

did not vary significantly with alley position although there was a tendency for MI at the 0–10 cm depth to be lower at the lower position in the alley where the Ap horizon was thickest.

3.4. Soil water transmissivity

Soil water transmissivity did not vary with treatment, but varied with position within alleys (Table 4). Soil in the hedgerow had the greatest transmissivity; the lower alley position had a higher transmissivity than the upper alley position ($P = 0.05$). The thicker Ap horizon in the lower alley enhanced water infiltration at that position. The soil in the hedgerow had not been tilled since its establishment 4 years earlier; it had also been protected from compaction by animal and human foot traffic since that time. Both the hedgerow and the lower alley accumulated soil material from higher elevations in the alley. The trapping of sediment by the hedgerow created a gradient in Ap horizon thickness. Within the 0–200 mm soil depth, drainable porosity, defined as those pores drained at a soil water pressure of -30 kPa, increased with decrease in alley elevation (discussed later). In addition to these two processes, soil in the lower alley also had a thicker root mass than that in the upper alley, created by greater root extension from the hedgerow (discussed later).

3.5. Soil water retention

Comparison of the field-measured (Fig. 3(A)) and laboratory-measured water retention curves (Fig. 3(B)) shows good agreement and that soil water was more tightly held at the upper alley position compared with the lower position. The range of plant available water, estimated as the soil water content at soil water pressure heads between -30 and -1500 kPa (Cassel and Nielsen, 1986), was 0.16 m^3 m^{-3}, 0.13 m^3 m^{-3}, and 0.08 m^3 m^{-3} for the lower, middle, and upper positions, respectively. Soil water content at the wilting point was greater for the upper than for the lower alley position. As there was a gradient in Ap horizon thickness among positions in the alley, the observed difference in soil water retention is probably due to differences in soil structure between the Ap and B horizons. The Ap horizon had a crumb structure, whereas the B horizon was more massive. This may be related to the greater organic matter content in the Ap

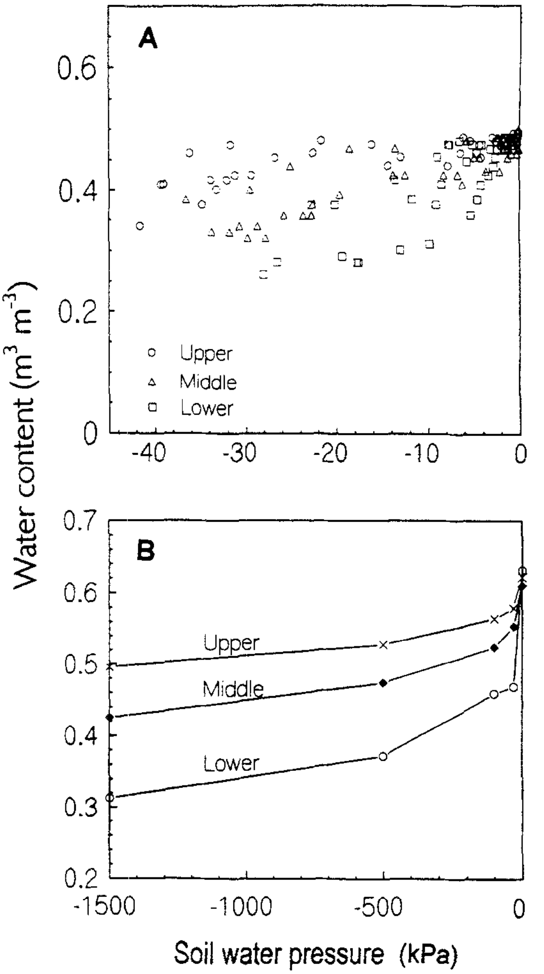

Fig. 3. Field-measured soil water characteristic for the 0–15 cm depth at three positions in the alleyway of Treatment GPas at Compact; (B) laboratory-measured soil water characteristic of 10–15 cm depth at three positions in the alleyway of Treatment Pen at Compact and Cabacungan.

horizon (Table 1) and better aggregate formation, analogous to the increase in available water reported by Lal (1989) for a coarse-textured soil under a hedgerow system.

3.6. Soil water pressure

Daily rainfall and soil water pressure head, hereafter denoted as pressure head, for the 15, 30, and 60 cm depths for Treatment GPas at the Compact site in the 1991 dry season are given in Fig. 4. As expected, pressure head increased (became less negative) with depth during this dry period because root density decreased with depth. The soil dried to the point that tensiometers at the 15 cm depth failed at most positions after Day 317 (13 November). Pressure heads at the 30 and 60 cm depths after this date were generally

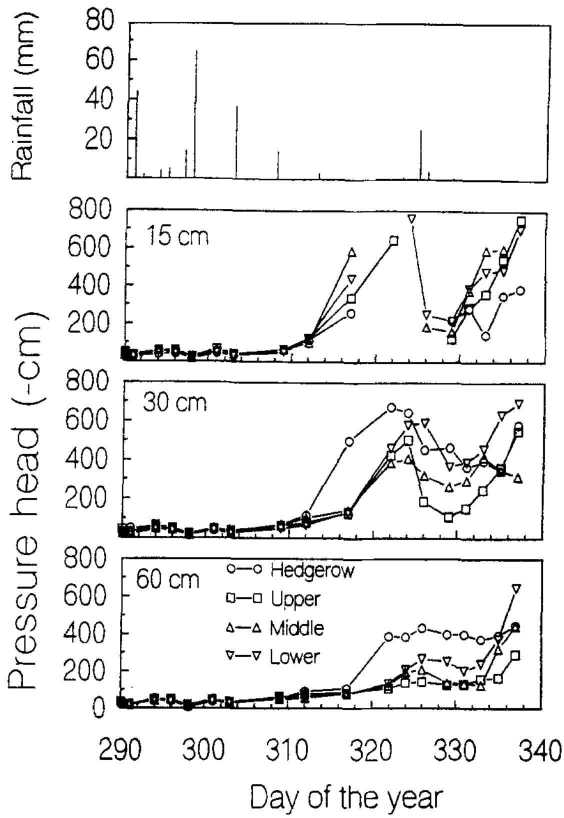

Fig. 4. Rainfall distribution and soil water pressure head for Treatment GPas in the 1991 dry season at the Compact site. Day of the year (DOY) 290 (17 October).

lower under the hedgerow than for the other positions, indicating greater water extraction under the hedgerow vegetation. Data for the Cabacungan site (not shown) were similar.

Spatial distributions of pressure head for the GPas treatment for 1 day in the wet and 1 day in the dry seasons, when all tensiometers were functioning, are shown in Fig. 5. On Day 203 (Fig. 5(A)) the pressure head at all depths at the Compact site was − 40 cm or more. A moderate soil water deficit condition existed on Day 331 (Fig. 5(B)). In general, pressure head at the 15 cm depth was more negative at the lower (Position 5) than at the upper alley position (Position 1). At soil depths below 30 cm, Position 5 had a lower pressure head than Position 1. The hedgerow (Position 0) also had a low pressure head. A pressure head difference at the 15 cm depth equal to 150–175 cm existed between Positions 0 and 1. This is equivalent to a 1.25 m m^{-1} lateral hydraulic gradient.

For depths below 30 cm the pressure head was lowest at Position 3, and was lower at Position 5 than at Position 0. However, at soil depths of 35 cm or more, the pressure head was lower at Position 0 and the difference increased with depth. As seen later, this

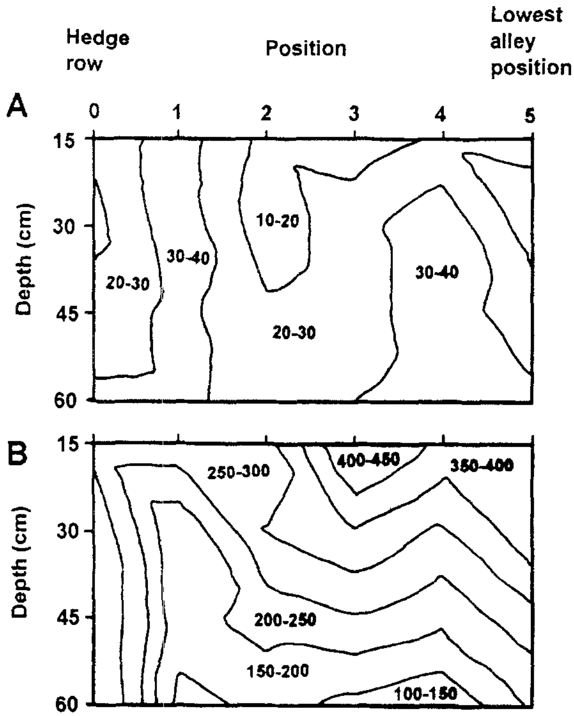

Fig. 5. Soil water pressure head (cm) distribution in Treatment GPas at the Compact site on (A) DOY 203 (wet season) and (B) DOY 331 (dry season), 1991.

behavior is related to the greater root mass in the upper 30 cm at Position 5 and the greater root mass below 35 cm at Position 0.

The spatial differences in pressure head for Treatment C (data not presented) was much smaller than for Treatment GPas. The pressure head on a wet day during the 1991 dry season ranged from −130 to −210 cm for Treatment C compared with −40 to −240 cm for Treatment GPas.

3.7. Soil water content

The soil water content distribution in the GPas plots as a function of position and soil depth is given for the Compact site in Fig. 6. Agreement between the pressure head (Fig. 5) and soil water content data (Fig. 6) is good. For example, Position 1 tended to have a greater water content than any other position, whereas Position 0 had the lowest water content within the 30–60 cm depth. The high soil water content at Position 1 is caused by less intensive root distribution, which is perhaps due to a more compact, massive, subsoil.

Soil water contents measured by TDR on 27 August 1992 vs. position for two soil depths for all five treatments during a short dry period are shown in Fig. 7. The rice crop was at the flowering stage and the last rain occurred 10 days earlier. Soil water content was not affected by hedgerow treatment or by treatment by position ($P > 0.05$).

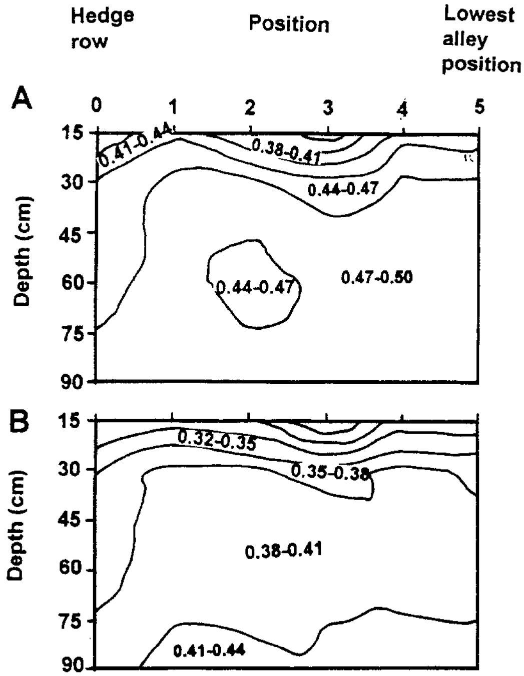

Fig. 6. Soil water content ($m^3 m^{-3}$) distribution in Treatment GPas at the Compact site on (A) DOY 204 (wet season), 1992 and (B) DOY 322 (dry season), 1991.

However, in all except Treatment C, soil water content was affected by position ($P = 0.01$). The lowest water contents occurred near the edges of the alleys. Water content did not vary among the three lowermost rows in the alley or between the two positions in the hedgerow.

3.8. Hedgerow and crop root length density

In general, root length densities for the mono-species hedgerows (Treatments G and Pen) were greater at the lower than upper alley position (Fig. 8). Soil movement downslope increased the Ap horizon depth immediately upslope from the hedgerow, creating a more favorable rooting environment.

For the GPas and GPen Treatments (data not shown) hedgerow root length was greater in the upper than in the lower position. Each hedgerow for these two treatments included a row of *Gliricidia* and a row of either *Paspalum* or *Penisetum* grass. The grass was always seeded on the downslope side of the *Gliricidia*. Thus the grass roots were favorably positioned to extend into the upper portion of the adjacent alley even though soil conditions might not be ideal. Competition by *Gliricidia* for water, light, and nutrients reduced grass root extension in the uphill side of the hedgerow. We did not separate *Gliricidia* roots from the grass roots but visual observation indicated that root length density at the upper alley position was dominated by the grass species. Because

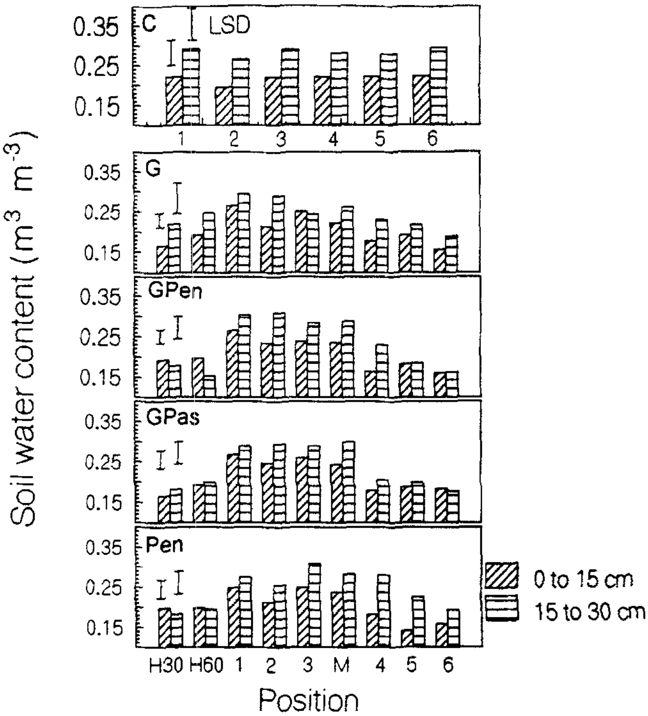

Fig. 7. Soil water content measured by TDR for the five treatments at two depths as a function of position. Measurements were taken on 27 and 31 August 1992. Each bar represents the mean of 12 measurements. The F-tests for position effect for Treatment C were not significant at $P = 0.05$. The LSD on the left is for the 0–15 cm depth; on the right, for the 15–30 cm depth.

the grass roots are much finer than *Gliricidia* roots, a given mass of grass roots would have a much greater root length density.

Based on the performance of the above-ground biomass of the food crop, which was greater in the middle of the alley than at either edge of the alley (Agus et al., 1997), we believe that the greatest root length density of the food crop occurred in the center of the alley, and decreased toward either hedgerow. The soil water pressure and water content data in Fig. 5 and Fig. 6 support this view. Total root length density of the hedgerow plus the food crop is therefore expected to gradually increase from the upper to the lower position of each alley in mono-species hedgerows. Therefore, total water extraction by the hedgerow and food crop combined is expected to be greatest in the lower alley, as was observed.

Published data on soil water distribution under alley cropping or hedgerow systems are sparse. Lal (1989) reported that the gravimetric water content in the 0–5 cm depth for an Alfisol in Nigeria was greater under an alley cropping system compared with an open field. Positions near the hedgerow were wetter, which was attributed to a windbreak effect of the hedgerow crop against dry winds. Our results do not agree with those of Lal, but the soil and climatic environments were different at the two sites. Our

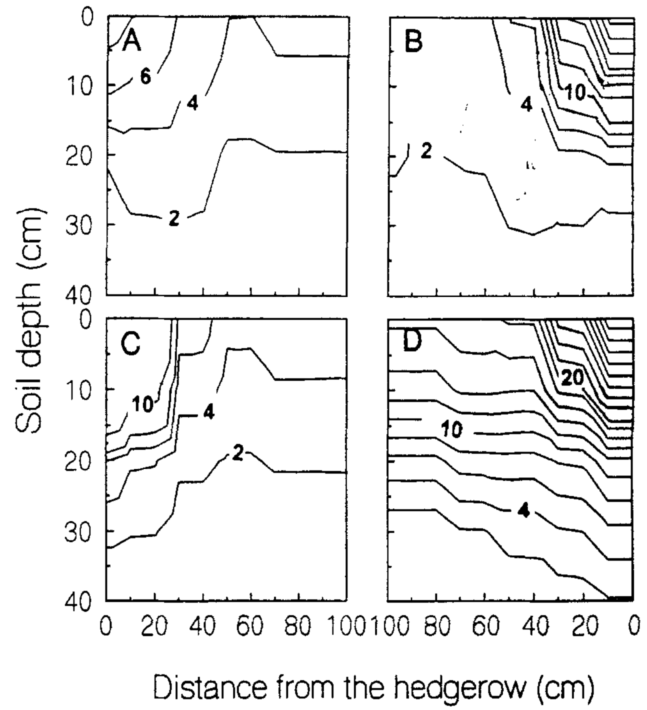

Fig. 8. Root length densities (km m^{-3}) in January 1992 for the *Penisetum* treatment at (A) Compact, upper alley position, (B) Compact, lower alley position, (C) Cabacungan, upper alley position, and (D) Cabacungan, lower alley position.

results do agree, however, with those of Singh et al. (1989), who observed the existence of severe competition for soil water between hedgerows of *Leucaena leucocephala* and food crops in a semi-arid region in India.

4. Summary

Installation of the contour hedgerow system trapped soil removed from the upper alley position and created a gradation in Ap horizon thickness, with thickness being greatest in the lower alley position. The upper alley position of the hedgerow treatments had less desirable soil physical properties than the lower position. Soil at the upper position held less plant available water and had a lower infiltration rate. Even though soil water content was often greater in the upper alley position, it was associated with lower soil water availability.

More work is needed to develop suitable management practices to avoid or alleviate the development of the negative soil physical properties and consequent deleterious effects on upper alley crop performance (Garrity, 1996). The time needed for soil properties to approach uniformity across the full width of the alley, or if they ever will, is not known. It is probable that the application of tree prunings and/or crop residues at the greater rate in the upper alley position may enhance soil aggregation and lead to a more uniform environment for the food crops across the entire alley. We believe that improved hedgerow management, the use of less competitive hedgerow species, and the choice of more drought-tolerant food crops for the late wet season, can further improve crop production and make hedgerow systems more acceptable management options for steep, highly erodible soils.

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