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Effect of hedgerow species in alley cropping systems on surface soil physical properties of an Oxic Paleustalf in southwestern Nigeria*

N. R. Hulugalle[1] and B. T. Kang

Soil scientists, IITA, Ibadan, Nigeria.

Sustaining the production base of farming, as well as increasing its productivity, involves a study of soil properties in relation to cropping practices/systems. Alley cropping, or the growing of tree crops in hedgerows with annual or seasonal food crops, has shown multiple benefits. This article, which reports the long-term effects of growing four tree species (two leguminous and two nonleguminous) on physical properties of the surrounding soil, finds those effects related to the quantity and quality of mulch specific to each tree species. It forms part of IITA's many studies on the role of alley cropping in improving agriculture in tropical Africa.

Introduction

Shifting cultivation and related bush fallow and slash-and-burn cultivation systems (1–3 years cropping alternating with 4–10 years of fallow) continue to be widely practiced by smallholder farmers in the humid tropics of Africa (Lagemann 1977; FAO 1978). Rapid population growth has, however, resulted in shortening of the fallow period in many areas, with a consequent increase in soil degradation and decline in crop yield (Lagemann 1977; FAO 1978). Alley cropping has been proposed as an alternative to shifting cultivation, to sustain crop production and reduce soil degradation (Kang et al. 1984, 1990). Alley cropping is the growing of food crops in alleys formed by hedgerows of trees or shrubs, preferably N-fixing leguminous species, that are pruned during the crop growing season to minimize shading of the food crops. The prunings are used as mulch or incorporated as green manure (Kang et al. 1981, 1984, 1985, 1990).

Alley cropping results in improvements in soil chemical properties and nutrient cycling, erosion control, and weed suppression, in addition to providing fodder, stakes, and firewood (Kang et al. 1981, 1984, 1985, 1990; Kang and Ghuman 1989; Mwenye 1984; Yamoah et al. 1986; Young 1986, 1987; Lal 1988). Information is sparse on the effects of alley cropping on soil physical properties, particularly with respect to the effects of hedgerow species. Results from a few studies conducted in

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1. Present address: IITA humid forest station, Mbalmayo, Cameroon.

southern Nigeria suggest that improvements in soil physical properties were greater with *Leucaena leucocephala* hedgerows than with *Gliricidia sepium* hedgerows (Kang and Ghuman 1989), and that *Cassia siamea* hedgerows were better than *Gliricidia sepium* and *Flemingia congesta* hedgerows (Yamoah et al. 1986). Compared with other treatments, alley cropping resulted in better soil physical properties (Yamoah et al. 1986; Kang and Ghuman 1989). The effects of other hedgerow species on soil physical properties are, however, unknown. This study quantified the long-term effects of alley cropping with two N-fixing leguminous species and two nonleguminous indigenous species on the surface soil physical properties of an Oxic Paleustalf in southwestern Nigeria. Observations were made in an ongoing trial established since 1981.

Materials and Methods

The experiment was conducted at the International Institute of Tropical Agriculture (IITA) site in Ibadan (7° 30'N, 3° 54'E) in the forest-savanna mosaic zone of southwestern Nigeria. Mean annual rainfall is 1250 mm, with a bimodal pattern. The rains usually commence in late March and continue until early November, with a short break during the July-August period. The dry season lasts from November to March.

The soil at the experimental site is a clayey, kaolinitic, isohyperthermic Oxic Paleustalf of the Egbeda series with a sandy loam topsoil and a sandy clay subsoil. A layer of angular and subangular quartz (gravel layer) occurs at a depth of 0.20-0.30 m (Moormann et al. 1975).

A randomized complete block design was used, with three replications. There were five treatments, consisting of four hedgerow species (*Leucaena leucocephala, Gliricidia sepium, Alchornea cordifolia*, and *Acioa barteri*) with interhedgerow spacings of 4 m and a control with no hedgerows. Within hedgerows, the plants were spaced at 0.25 m intervals. Plot size was 6 x 24 m. All plots received fertilizer at a rate of 45 kg N, 20 kg P, and 20 kg K per hectare. Fertilizer was applied only to the main season (April-July) crop, maize *(Zea mays)*. No fertilizer was applied to the minor season (August-October) crop, cowpea *(Vigna unguiculata* Walp.). A minimum tillage system was used (Lal 1987). Preplanting land preparation was done by spraying 0.5 kg ha^{-1} a.i. paraquat, followed by hand pruning of the hedgerows and application of the prunings as mulch in the interhedgerow spaces. Crops were planted at a population of 40,000 plants ha^{-1}. Hedgerows were pruned at 6-8 week intervals during the growing season.

Soil physical measurements were carried out before and during the maize cropping season of 1989. Five soil cores (50 mm high and 51 mm in diameter) were randomly collected from the 0-0.05 m depth in all plots on 31 January and 6 June. They were taken to the laboratory and saturated by capillarity for 48 h. Soil water retention at saturation, and at potentials of −10 kPa, −100 kPa, and −1500 kPa were determined using pressure plate apparatus (Klute 1986). Penetrometer resistance in the 0-0.02 m depth was determined on the same cores after they had equilibrated at these moisture potentials, as described by Hulugalle and Rodriguez (1988). Bulk density of the cores was determined after oven drying at 105°C. Apparent pore-size distribution was inferred from the soil water retention characteristics using the capillary rise equation $\psi = -2\sigma/r\rho_w$, where ψ is soil water potential, r is the radius of the curvature of the interface (i.e., pore radius), σ is the surface tension, and ρ_w is the density of water (Campbell 1985). Composite soil samples taken from the 0–0.05 m depth of all plots on 31 January 1989 were air dried, ground, and passed through a 2-mm sieve; particle size distribution was determined with the hydrometer method (Klute 1986). Diurnal variation in soil temperature at a depth of 0.05 m was monitored with mercury-in-glass bent stem-soil thermometers on 3 February, 2 March, 4 April, 27 April, 25 May, and 4 July 1989. Soil water content in the 0.02-0.07 m depth adjacent to the thermometer was concurrently measured by gravimetric sampling at 1400 hours on the same days. Water infiltration was measured over a 2 h period in February with a double-ring infiltrometer. Water infiltration results were analyzed following Philip's equation, $i = S/(2\sqrt{t}) + A$, where S is sorptivity, A is transmissivity, t is time, and i is infiltration rate (Philip 1957). All data were analyzed by analysis of variance for a randomized complete block design (Little and Hills 1978).

Results and Discussion

Particle size distribution. Particle size distribution was not significantly affected by any of the experimental treatments (Table 1). This result is in contrast to other studies, which indicate that soil erosion rates and, hence, losses of the fine soil component (silt + clay) are lower with alley cropping (Lal 1988; Kang and Ghuman 1989). Exposure of the clay-rich subsoil with the higher erosion rates in the control, however, may have resulted in similar values of sand, silt, and clay contents (Lal 1976).

Table 1. Effect of hedgerow species on particle size distribution (%) in the 0-0.05 m depth of an Oxic Paleustalf in Ibadan, Nigeria, on 31 January 1989.

	Particle size distribution		
Hedgerow species	Sand	Clay	Silt
Gliricidia sepium	72.7	14.7	12.6
Alchornea cordifolia	76.0	12.0	12.0
Leucaena leucocephala	76.0	12.7	11.3
Acioa barteri	76.0	12.7	11.3
Control	74.7	12.7	12.6
± SE	1.84	0.74	0.92

Soil bulk density. Bulk density in the 0-0.05 m depth was not significantly affected by date of sampling (Table 2). Bulk density averaged over both dates of sampling was lowest with *L. leucocephala*, and highest in the control ($P < 0.05$). This may have been due to addition of large amounts of *L. leucocephala* prunings as mulch and the absence of such additions in the control (Table 3). Mulching is known to improve soil physical properties (Lal 1987). Bulk density did not differ significantly between alley-cropped plots.

Table 2. Effect of hedgerow species on soil bulk density (Mg m^{-3}) in the 0-0.05 m depth of an Oxic Paleustalf in Ibadan, Nigeria, in 1989.

	Bulk density		
Hedgerow species	31 Jan	6 Jun	Mean
Gliricidia sepium	1.31	1.34	1.33
Alchornea cordifolia	1.36	1.43	1.40
Leucaena leucocephala	1.26	1.35	1.31
Acioa barteri	1.31	1.36	1.34
Control	1.36	1.46	1.41
Mean	1.31	1.39	

± SE: Between dates = 0.024; between hedgerow species = 0.031; between hedgerow species for same date = 0.044; between hedgerow species for different dates = 0.046.

Table 3. Biomass dry weight (t ha^{-1}) of prunings[1] of hedgerows during the main season in 1989 in Ibadan, Nigeria.

Hedgerow species	Pruning date 10 Apr	22 May	27 Jun	Total
Gliricidia sepium	1.08	2.03	0.42	3.53
Alchornea cordifolia	2.48	0.99	-	3.47
Leucaena leucocephala	2.43	1.33	0.63	4.39
Acioa barteri	2.76	-	-	2.76
± SE	0.31	0.16	0.07	0.37

1. Includes leaves and young green parts of the stem.

Soil water retention, apparent pore-size distribution, and penetrometer resistance. Soil water content at saturation in the 0-0.05 m depth on 31 January was in the order *L. leucocephala* > *A. barteri* = *G. sepium* = *A. cordifolia* > control ($P < 0.01$) (Fig. 1). On 6 June it was in the order *L. leucocephala* = *G. sepium* > *A. barteri* = *A. cordifolia* = control ($P < 0.05$). The water content values at saturation in the various treatments appear to reflect the quantities of prunings returned as mulch (Table 3). Lal (1987) also reported that water content at saturation increased in proportion to the weight of mulch applied. Soil water content at −10 kPa did not differ significantly between treatments on 31 January, but was significantly greater ($P < 0.05$) in *A. cordifolia* plots on 6 June than in other treatments. This was primarily due to a higher increase in the proportion of micropores (pore radius, $r < 1.4$ µm) in *A. cordifolia* plots, as will be discussed later.

Pore-size distribution in the 0-0.05 m depth differed significantly ($P < 0.01$) with date of sampling. Measurements on 31 January and 6 June showed that the proportions of macropores and micropores decreased and increased, respectively, with time (Table 4). Proportions of mesopores (r = 1.4-14.4 µm) were, however, not significantly affected (Table 4). The decrease in proportions of macropores and increase in micropores was largest with *A. cordifolia* hedgerows.

Penetrometer resistance in the 0-0.02 m depth at −10 kPa did not differ significantly between treatments on either 31 January or 6 June (Fig. 2). At −100 kPa and −1500 kPa, the largest values of penetrometer resistance were observed on both sampling dates in the control and *A. cordifolia* plots. At the same potentials on 31 January, penetrometer resistance was significantly lower ($P < 0.05$) in *L. leucocephala* plots than in all other treatments. Decreases in penetrometer resistances at potentials of −100 kPa and −1500 kPa were observed in *L. leucocephala*, *G. sepium*, and *A. barteri* plots over the period 31 January to 6 June. The higher penetrometer resistances in the control and *A. cordifolia* plots suggest that surface crusting was greatest with these treatments.

The above changes in soil water retention, pore-size distribution, and penetrometer resistance indicate the degree of soil compaction and crust formation that occurred between 31 January and 6 June.

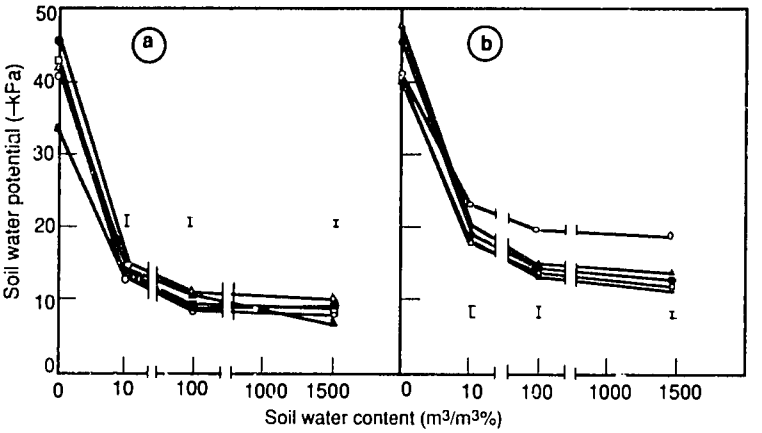

Figure 1. Effect of hedgerow species on soil water retention in the 0-0.05 m depth of an Oxic Paleustalf in Ibadan, Nigeria on (a) 31 January and (b) 6 June 1989. (Δ) *Gliricidia sepium*; (o) *Alchornea cordifolia*; (●) *Leucaena leucocephala*, (□) *Acioa barteri* (▲) control; I = SE of mean.

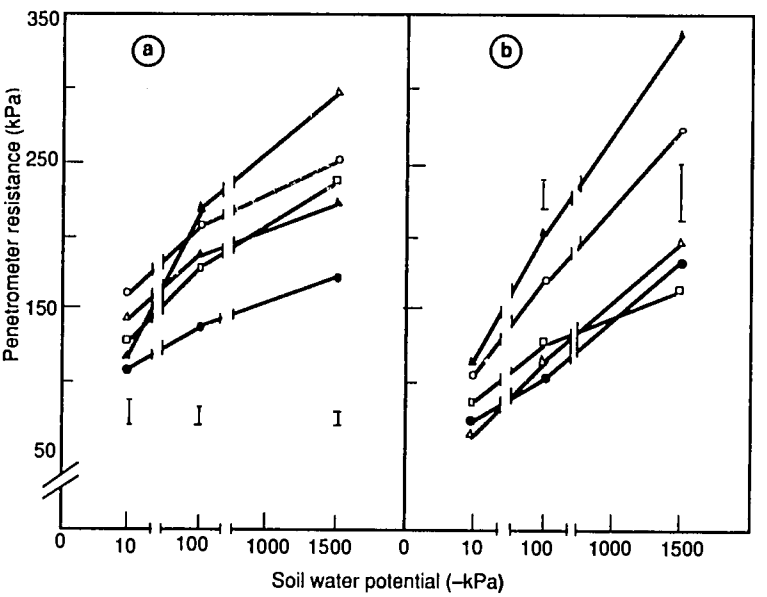

Figure 2. Effect of hedgerow species on penetrometer resistance in the 0-0.02 m depth of an Oxic Paleustalf in Ibadan, Nigeria, on (a) 31 January and (b) 6 June 1989.(Δ) *Gliricidia sepium*; (o) *Alchornea cordifolia*; (●) *Leucaena leucocephala* (□), *Acioa barteri* (▲) control; I = SE of mean.

Table 4. Effect of hedgerow species on the percentage of macropores, mesopores, and micropores in the 0-0.05 m depth of an Oxic Paleustalf in Ibadan, Nigeria, in 1989.

Hedgerow species	31 Jan	6 Jun	Mean
Macropores (pore radius > 14.4 μm)			
Gliricidia sepium	69.2	62.2	65.7
Alchornea cordifolia	73.8	54.2	64.0
Leucaena leucocephala	72.5	63.0	67.8
Acioa barteri	71.9	65.5	68.7
Control	71.6	62.8	67.2
Mean	71.8	61.5	
± SE:	Between dates = 0.55; between hedgerow species = 2.04; between hedgerow species for same date = 2.89; between hedgerow species for different dates = 2.64.		
Mesopores (pore radius 1.4-14.4 μm)			
Gliricidia sepium	12.1	9.7	10.9
Alchornea cordifolia	10.3	8.3	9.3
Leucaena leucocephala	12.0	8.5	10.2
Acioa barteri	11.1	8.0	9.6
Control	11.3	11.2	11.2
Mean	11.4	9.1	
± SE:	Between dates = 0.53; between hedgerow species = 0.76; between hedgerow species for same date = 1.07; between hedgerow species for different dates = 1.09.		
Micropores (pore radius < 1.4 μm)			
Gliricidia sepium	18.7	28.1	23.4
Alchornea cordifolia	15.8	37.5	26.7
Leucaena leucocephala	15.5	28.5	22.0
Acioa barteri	17.3	26.5	21.9
Control	17.1	26.1	21.6
Mean	16.9	29.3	
± SE:	Between dates = 0.17; between hedgerow species = 1.60; between hedgerow species for same date = 2.26, between hedgerow species for different dates = 2.03		

Table 5. Effect of hedgerow species on water infiltration characteristics, measured in February 1989, of an Oxic Paleustalf in Ibadan, Nigeria.

	Infiltration characteristics		
Hedgerow species	Sorptivity[1] (mm min$^{-0.5}$)	Transmissivity[2] (mm min^{-1})	Infiltration rate[1] at 2 h (mm min^{-1})
Gliricidia sepium	28.22 (3.34)	1.49 (2.44)	2.53 (0.93)
Alchornea cordifolia	12.81 (2.55)	1.46 (0.43)	1.96 (0.67)
Leucaena leucocephala	31.50 (3.45)	0.10 (2.31)	1.59 (0.46)
Acioa barteri	24.78 (3.21)	2.08 (2.49)	2.87 (1.05)
Control	38.86 (3.66)	-1.03 (2.19)	0.79 (-0.23)
±SE	(0.300)	(0.066)	(0.20)

1. Values in parentheses are log-transformed values of (x) where (x) is the untransformed value.
2. Values in parentheses are log-transformed values of $(10+x)$ where (x) is the untransformed value.

Soil compaction and crusting in nonmechanized farming systems result from human traffic during planting, pruning, weeding, and fertilizer application, and from high-intensity rainfall which occurs in humid tropical regions (Lal 1987). The differential soil compaction and crusting between treatments reflect the pruning frequency, and the quantity and quality of prunings retained as mulch. *L. leucocephala* and *G. sepium* hedgerows produce large quantities of easily decomposable prunings at frequent intervals, whereas *A. barteri* produces smaller quantities of slowly decomposable prunings less frequently (see earlier discussion and Mwenye 1984). The net effect is, however, similar, since the soil surface is effectively protected from the compactive effects of both rainfall and traffic for extended periods by the prunings of *L. leucocephala*, *G. sepium*, and *A. barteri*. *A. cordifolia*, which produces only moderate quantities of moderately decomposable prunings (Mwenye 1984) compared to *L. leucocephala*, *G. sepium*, and *A. barteri*, provides less protection to the soil surface. Soil compaction is, therefore, higher in *A. cordifolia* plots during the growing season.

Water infiltration characteristics. Sorptivity determined during the dry season in February 1989 did not differ significantly between treatments (Table 5). Transmissivity and infiltration rates at 2 h were, however, significantly larger ($P < 0.05$) in alley-cropped treatments. The increases in infiltration rate and transmissivity may have been due to an increase in the number of subsurface transmission pores ($r > 50$ μm) caused by decaying roots and high earthworm populations, both of which are features of alley cropping systems (Ball 1985; Kang et al. 1990).

Diurnal variation in soil temperature. Soil temperature at a depth of 0.05 m was significantly lower in *L. leucocephala* plots on 3 February ($P < 0.01$) and 4 April ($P < 0.05$), and in *A. barteri* plots on 27 April ($P < 0.01$) (Fig.3) than in the other treatments. On 25 May, soil temperatures in *A. barteri* and *L. leucocephala* plots were significantly lower ($P < 0.01$) than in the control. The differences in soil temperature on each day of measurement were related to differences in soil water content. Soil temperature was related to soil water content in the 0.02-0.07 m depth q (m^3 m^{-3}%) thus:

$$T_{max} = 40.20 \exp(1.60 \times 10^{-2}\,\theta),$$
$$r^2 = 0.70^{***}\ (P = .001),\ n = 90;$$

where T_{max} is maximum diurnal soil temperature (°C) at a depth of 0.05 m. High soil water contents are known to have a 'damping' effect on soil temperature (Campbell 1985). Differences in soil water content in turn were attributable to differences in ground cover, either from better growth and shading effect of the shrubs (e.g., 2 February and 4 April) (Mwenye 1984) or from thicker mulch provided by prunings of the shrubs (27 April and 25 May), which created differen-

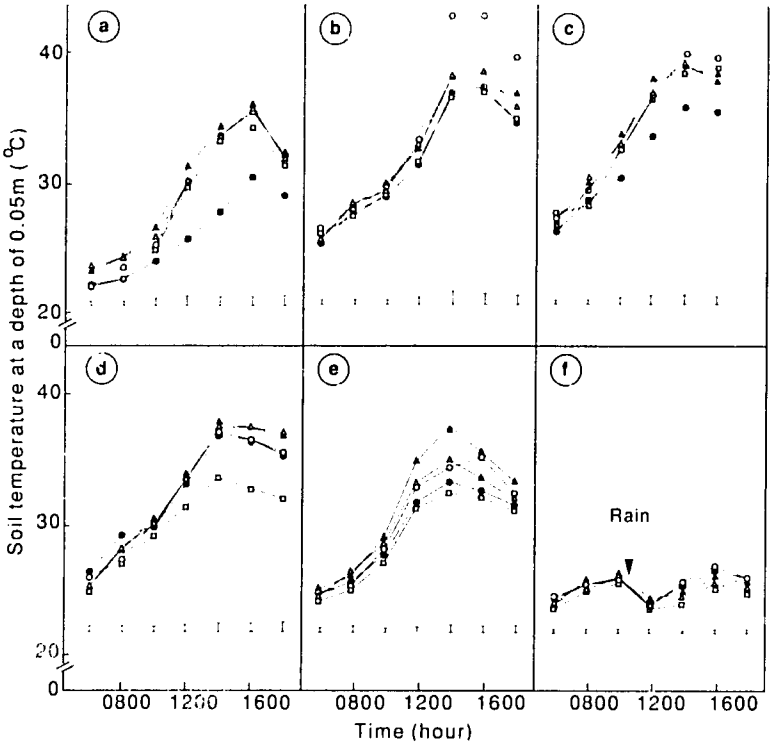

Figure 3. Effect of hedgerow species on diurnal variation in soil temperature at a depth of 0.05 m in an Oxic Paleustalf in Ibadan, Nigeria on (a) 3 February, (b) 2 March, (c) 4 April, (d) 27 April, (e) 25 May, and (f) 4 July 1989. (Δ) *Gliricidia sepium*; (o) *Alchornea cordifolia*; (●) *Leucaena leucocephala* (□), *Acloa barteri* (▲) control; I = SE of mean.

tial patterns of soil water evaporation. When soil water content was very low (2 March) or very high (4 July), ground cover did not result in differences in soil water content, and hence soil temperature.

Conclusions

Soil compaction and maximum diurnal temperatures were lower and water infiltration greater with alley cropping than in the control. Among the hedgerow species studied, soil compaction was, in general, lower with *L. leucocephala* hedgerows, although *A. barteri* hedgerows had an ameliorative effect on soil temperature. It should be noted, however, that the differential effects of hedgerow species and the control on surface soil physical properties, in addition to being caused by direct short-term treatment effects as discussed, may in part also be due to long-term cumulative treatment effects. Some of the factors that affected surface soil physical properties were pruning frequency, and quantity and quality of the prunings produced by the hedgerows. Improvements in soil physical properties were more likely to occur when a shrub produced either large quantities of easily decomposable prunings frequently or smaller quantities of slowly decomposable prunings less freqaently. Hedgerow species that can frequently produce large quantities of prunings which decompose slowly may, therefore, be the most desirable for alley cropping systems.

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