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Indices of root and canopy growth of leguminous cover crops in the savanna zone of Nigeria

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Abstract

This study was carried out in 1994 in the derived (DS) and northern Guinean savanna (NGS) zones of Nigeria at about 17–18 weeks after planting forage legumes. The forage legumes, which included *Cajanus cajan*, *Crotalaria ochroleuca*, *Stylosanthes hamata*, *Centrosema pascuorum*, *Lablab purpureus*, *Mucuna pruriens* (black and white) and *Pueraria phaseoloides,* were treatments in the randomised complete block design. Root morphology and length were evaluated for the 2 zones, but light received under canopies, soil temperature and soil water potential were measured only in the DS. Roots on soil profile walls were traced, and in the laboratory, computer software was used to evaluate root length after scanning. Canopy coverage was evaluated using a light meter. In the DS, the presence of gravel in the subsoil modified the morphology and distribution of roots even for the same species compared with the root architecture in the NGS zone. A hardpan in the shallow soil layers in the NGS caused a proliferation of roots in the topsoil, and a tendency for increased diameter (visual observation) of the primary roots. Total root length ranged from 834–1861 mm in the DS, and 939–1277 mm in the NGS, and was similar in both locations. Legume canopies intercepted 81–99% of sunlight, suggesting that they had the potential to maximise sunlight for their growth under adequate soil moisture and nutrient in the moist savanna. Legumes such as *C. cajan*, *L. purpureus*, *M. pruriens* and *P. phaseoloides* with potential to grow roots beyond 60 cm depth and which intercepted ≥ 95% of incident sunlight were recommended for sustained growth and rapid regeneration after cutting or browsing. Furthermore, the legumes can be combined with shallow-rooted crops for enhanced crop production in a crop-livestock farming system or in pasture, based on the differences in their root and canopy growth.

Introduction

Forage legumes improve soil fertility through nitrogen fixation. As cover crops, they prevent soil erosion. The characteristics of the species and the environment in which they grow influence forage or pasture quality. Thus, leguminous cover crops may not be required for their agronomic potential alone, but for other uses which include livestock production (Tarawali *et al.* 1999; Muhr *et al.* 1999a, 1999b, 1999c).

These various uses and capability of leguminous (inter-row planted) cover crops indicate that they are important for the sustainability of cropping systems in the tropics. They can prevent rapid soil degradation, improve soil productivity (Vine 1953; Wilson *et al.* 1982; Carsky *et al.* 1999; Tian *et al.* 1999) and can be used to promote crop-livestock farming in the tropics (Humphreys 1991). They have the potential to influence crop yields either positively (*e.g.* supply of nitrogen) or negatively (*e.g.* competition for soil resources and light). Agboola and Fayemi (1971) reported that, while maize yield was not affected by intercropping, the legume yield was significantly suppressed by maize shade. Becker and Johnson (1999) found that the influence of leguminous cover crops on upland rice yield depended on the time of introducing the legumes into the rice fields.

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For livestock production, leguminous cover crops should produce adequate herbage (Humphreys 1991) and should be able to withstand some level of defoliation by grazing animals or livestock farmers (Tarawali *et al.* 1995). Persistence of the legumes during the dry season is desirable (Muhr *et al.* 1999a; Peters *et al.* 2000). According to Humphreys (1991), pasture growth is limited by the amount of light intercepted by canopies if soil nutrients and water are adequate, and a 95% sunlight interception is generally regarded as a critical value. Utilisation of soil resources to produce herbage of high quantity and quality, and the persistence of the legumes in the dry season depend on root growth. However, information on this is scanty because root growth is rarely studied. This is particularly so in the humid and subhumid zones of Nigeria where characterisation of these legumes for crop (Weber 1996; Obiagwu 1997a, 1997b; Becker and Johnson 1999) or livestock production (Tarawali *et al.* 1995; 1999) usually focused on above-ground characteristics.

Competition between inter-row planted legumes and the intercrops is related to below- and/or above-ground characteristics of the legumes. For instance, canopies of legumes influence yields through shading, and promotion of pest problems in intercropping systems (Muchow 1985; Fukai and Cenpukdee 1992; Agboh-Noameshie *et al.* 1997).

Soil temperature influences the softening of legume seeds for pasture regrowth while light-sensitive seeds will not germinate under dense canopies (Humphreys 1991). Both soil temperature and light penetration will vary with changes in pasture canopy densities caused by grazing or cutting for livestock production.

Soil water extraction by plant roots and soil temperature changes due to sunlight penetration through the pasture canopy will further influence soil water potential (Ghildyal and Tripathi 1987). Armstrong *et al.* (1999) and Salako and Tian (2000) reported that soil water demand varied with growth stage of the cover crop and the species of legume used.

Traditional measurement of root characteristics usually involves destructive and tedious sampling and evaluation procedures (Böhm 1979; Anderson and Ingram 1993), so few studies are conducted. Less tedious scanning techniques are now available after which root parameters are evaluated with computer software (Kirchhof and Pendar 1993).

This study was part of a broad-based characterisation of leguminous cover crops in the moist savannas of Nigeria carried out by the International Institute of Tropical Agriculture, Ibadan, Nigeria. Some aspects have been reported by Kolawole and Kang (1997), Tian and Kang (1998), Carsky *et al.* (1999) and Tian *et al.* (2000). We aimed to describe the morphology of the roots, and evaluate canopy growth of the various leguminous cover crops in an endeavour to help in selecting appropriate cover crops for integration into the farming systems of the zone.

Materials and methods

Sites and experimental design

Two sites, established in 1994, were used in this study. One was located in Alabata village, near Ibadan (7° 35′N, 3° 52′ E), south-western Nigeria, and the other in Kasuwa Mangani, southern Kaduna (10° 24′N, 7° 42′ E), northern Nigeria (Figure 1). The south-western site is in the savanna/forest transition zone or derived savanna (DS) whereas the northern site is in the northern Guinean savanna (NGS). Annual rainfall at both sites is about 1300 mm. Gravel content of the soil profile in the DS was pronounced (Table 1) whereas gravel and hardpans were found at shallow layers (15–60 cm depth) in the NGS. Using the United States Department of Agriculture classification (Ghildyal and Tripathi 1987), the soil profile gravel in the DS was a mixture of fine (2–10 mm) and coarse (> 10 mm) quartz gravel while fine gravel (iron concretion) was dominant in the NGS. The NGS site had 500 g/kg sand, 200 g/kg silt, and 300 g/kg clay (Carsky *et al.* 1999). Surface soil bulk density was 1.2 Mg/m^3 in the DS and 1.5 Mg/m^3 in the NGS. Soils at both sites were Alfisols. Soil chemical characteristics, field operations, legume and crop performance at the 2 sites have been reported by Tian and Kang (1998), Carsky *et al.* (1999) and Tian *et al.* (2000).

A randomised complete block design was used at both sites, with 4 replications in the DS and 3 in the NGS. Plot size was 8 m × 12 m, and plant spacing was 0.75 m × 0.25 m. The leguminous cover crops (treatments) for this study were *Cajanus cajan*, *Crotalaria ochroleuca* (erect or shrub legumes); *Centrosema pascuorum*, *Lablab*

Table 1. Particle size and gravel distribution in a soil profile at Alabata, south-western Nigeria[1].

Soil depth	Particle size distribution[2]		Air-dried soil gravel content[3]	Soil chemical properties[4]	
	Sand	Clay		pH (1:1 H_2O)	Organic carbon
(cm)	(g/kg)		(g/kg)		(g/kg)
0–19	854	56	72	6.0	6.5
19–50	762	135	396	5.8	4.1
50–73	605	312	227	5.4	3.5
73–114	580	327	155	5.5	3.0
114–170	617	257	70	5.7	2.7

[1] Source: Salako, F.K., Tian, G. and Akinbola, G.E. (unpublished data).

[2] Particle size distribution was determined by the pipette method (Gee and Bauder 1986).

[3] Fine gravel (2–10 mm) was evaluated as a proportion of air-dried soil sample; coarse gravel (>10 mm) was present mainly below 50 cm depth.

[4] pH and organic carbon (Walkley-Black method) were determined by methods described in IITA (1979).

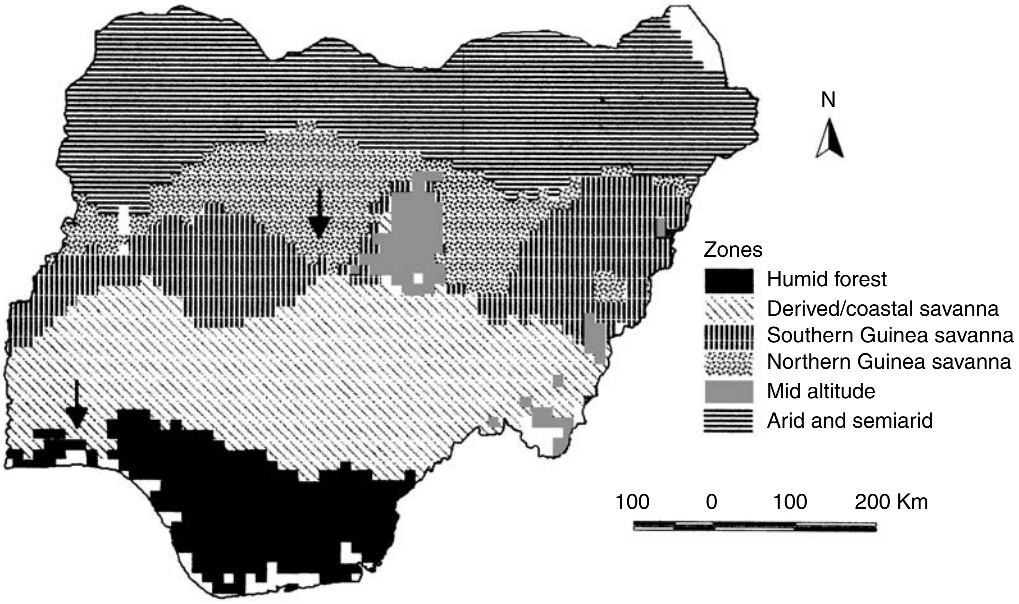

Figure 1. The experimental sites in south-western and northern Nigeria (indicated by arrows), and the various agro-ecological zones of the country (Source: Crop Modeling Unit, Resource and Crop Management Division, International Institute of Tropical Agriculture, Ibadan, Nigeria).

purpureus, *Mucuna pruriens* (black and white), and *Pueraria phaseoloides* (creeping herbaceous legumes).

Natural fallows of *Chromolaena odorata* (about 1 year old) and *Imperata cylindrica* (same age as legumes) were included as control treatments in south-western Nigeria. *Imperata cylindrica* infestation was prevalent on this recently cultivated site. Although the experiment was sited in the area infested with *I. cylindrica*, there was an adjacent fallow site where *C. odorata* was dominant. Therefore, *I. cylindrica* regrowth alone was on the natural fallow plots of the experiment. *Chromolaena odorata* was included because it represented the dominant natural fallow species for fallow periods less than 5 years in the DS.

Root morphology and distribution study

Roots of single leguminous cover crops were studied at 17 weeks after planting (WAP) in the DS, and at 18 WAP in the NGS. In the DS, 2 mid-replications of the 4 replications were used whereas 3 replications were used in the NGS. Selection was limited due to logistical reasons.

The profile wall method (Böhm 1976; 1979) was used for root study. Roots of single plants were traced from the top down the profile depth. Profiles were dug to reach 200 cm depth if possible; otherwise, they were dug to where impediments were encountered. The exposed roots were mapped by a combination of dots, and tracing with markers on a transparent foil attached to a grid (10 × 10 cm) frame (50 × 100 cm) fixed to the profile wall. All roots visible to the naked eye and those seen with the aid of a hand lens were mapped. Although the roots exposed on each wall belonged to different stems, those mapped were linked by tracing from the soil surface with the stem of the plant to be mapped. Thus, 1 plant per species in each replication was mapped.

In the laboratory, the mapped roots were resolved to scale on a linear graph sheet before being transferred to quarto-sized transparencies. These scaled roots were scanned with Delta-T scan for the evaluation of root length, as would have been done with photocopies for an indirect evaluation of root length with computer software (Kirchhof and Pendar 1993). Thus, an indirect evaluation of root length was carried out.

Light penetration though legume canopies, soil temperature and water potential

Light penetration through canopies, soil temperature and water potential were studied only in the DS zone for logistical reasons. At 18 WAP, the legumes (>60 cm height) were evaluated for light penetration through their individual canopies with a light meter (LI-COR-1000) placed on the ground in mid-rows under the canopies between 10.00 and 11.00 h. The 4 replications at the site were used.

Soil water potential was measured with vacuum gauge tensiometers between 20 and 24 WAP on the same plots where roots were mapped. A tensiometer was installed at 15 cm and 30 cm depths on each plot.

Soil temperature was measured with a soil thermometer installed at 5 cm depth in each plot during this period; the measurements were taken at 13.00 h. Although rainfall events of 14 mm were recorded on October 31 and November 3, 1994 (at the meteorological station of International Institute of Tropical Agriculture, Ibadan, about 20 km south of the DS site), the last significant rainfall (31 mm) was recorded on October 25, 1994. Thus, the period, October 27–November 22, 1994, was the end of the rainy season at the DS site.

Analysis of data

Rooting depths of legumes in 8 soil profiles in the DS and 15 profiles in the NGS were compared. The data were analysed using the mixed model of SAS with the Satterthwaite option and the means were separated by paired comparisons or the PDIFF option (Littel *et al.* 1996). Least significant difference at 5% probability level ($LSD_{0.05}$) was also calculated. Simple linear regression was carried out to evaluate relationships of parameters.

Results

Root morphology and distribution

Root morphology and distribution of the shrubs, *C. cajan* and *C. ochroleuca*, were influenced by gravel distribution in the soil profile (Table 1; Figures 2 and 3). In Figures 2–5 and Figure 7, the term ‘gravelly’ indicates the depth below which very severe restriction to root growth by gravel was encountered, although gravel was found generally in all soil horizons (Table 1). The roots grew through a loamy sand topsoil and a sandy clay loam or sandy loam subsoil (Table 1). The gravelly subsoil (Figures 2 and 3) contained fine (2–10 mm) and coarse (>10 mm) gravel. *Cajanus cajan* grew beyond 90 cm (Figure 2; Table 2) depth while the maximum rooting depth for *C. ochroleuca* was 85 cm (Figure 3). The presence of the coarse gravel limited root abundance of the shrubs beyond 80 cm depth.

Table 2. Maximum rooting depth of forage legumes at 17 weeks after planting (WAP), light received (% of full sunlight) under their canopies at 18 WAP and mean surface soil (5 cm depth) temperature between 20 and 24 WAP in 1994 in south-western Nigeria.

Legumes	Maximum rooting depth	Light received under canopy	Surface soil temperature
	(cm)	(%)	(°C)
C. cajan	> 90	4.9	27.3
C. ochroleuca	85	13.1	29.7
L. purpureus	> 100	3.8	—
M. pruriens (black)	70	1.0	28.5
P. phaseoloides	70	1.0	27.0
C. pascuorum	—[1]	18.7	30.2
Bare surface	—	92.7	37.7
C. odorata	60	—	25.9
$LSD_{0.05}$	—	9.7	0.9

[1] Not included.

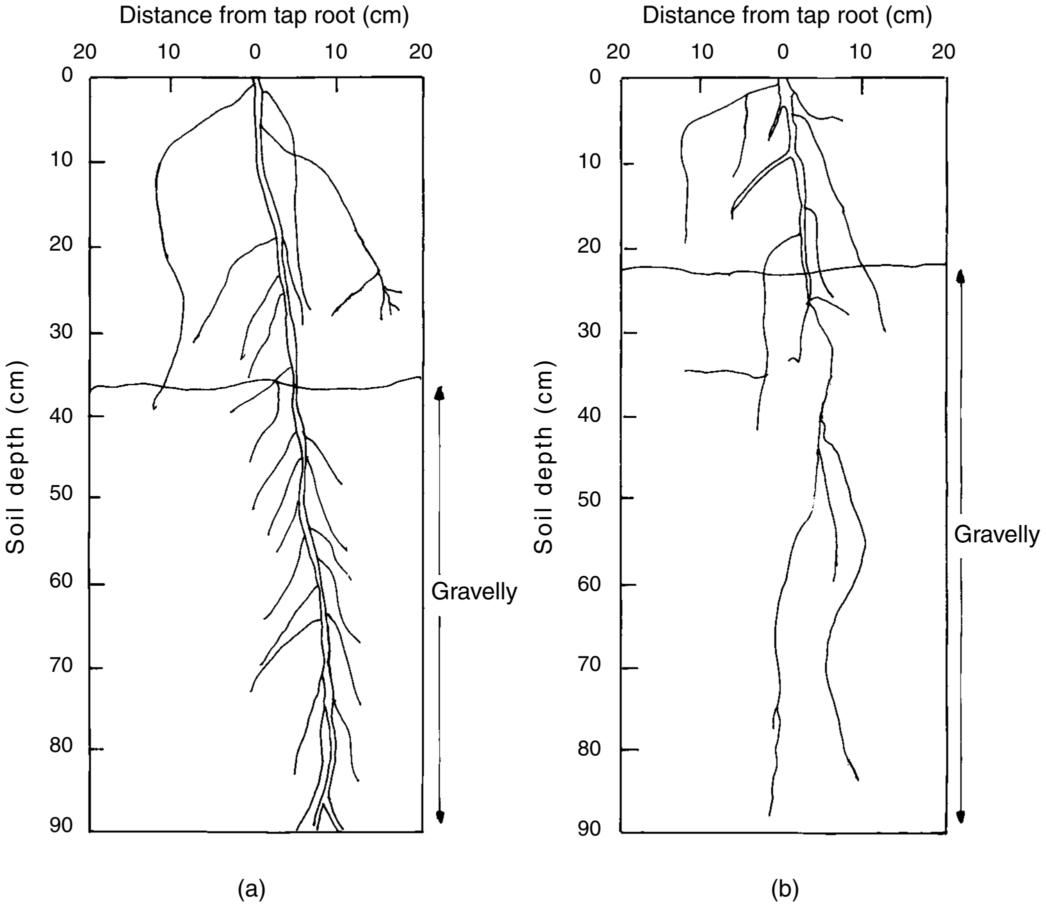

Figure 2. Spatial variation in root morphology and distribution of *Cajanus cajan* at 17 weeks after planting in Alabata, a derived savanna zone of south-western Nigeria; major gravelly impediments below (a) 30 cm; and (b) 20 cm soil depths.

Mucuna pruriens (black) roots did not grow beyond 70 cm soil depth even without a gravelly restriction (Figure 4). *P. phaseoloides* had a maximum rooting depth of 70 cm (Table 2) in a profile (not shown) while *L. purpureus* roots grew up to 110 cm profile depth (Table 2; Figure 7) when gravelly restriction was not encountered in the root zone. Natural fallows of *I. cylindrica* (Figure 5a) and *C. odorata* (Figure 5b) had roots which grew laterally, and these were mapped as dots where the cut tips of individual roots protruded on the profile wall. Restriction by gravel might have impeded growth of *I. cylindrica* at about 30 cm depth but this could not be said of the *C. odorata* profile where there was no impediment by gravel.

Roots in the NGS were deflected at shallow depths as they came in contact with hardpans, and the roots tended to proliferate within the available soil volume (Figure 6). Gravel in the NGS was made up of iron concretions. ‘Hardpan’ in Figures 6 and 7 implied an impenetrable soil layer which could not be dug and which restricted root growth. Above the hardpan were iron concretions (gravel) diffused in the sandy clay loam (texture determined by feel) soil. *Mucuna pruriens* (white) roots did not exceed 30 cm depth in Figure 6a because of the impenetrable layer of hardpan at this depth. This observation was also true for root growth of *M. pruriens* (black) at this site (soil profiles not shown). However, in two soil profiles of *M. pruriens* (one for the white and the other for the black) dug up to 50 cm depth before coming in contact with hardpan, the rooting depth of the legume was about 45 cm. *Cajanus cajan* root

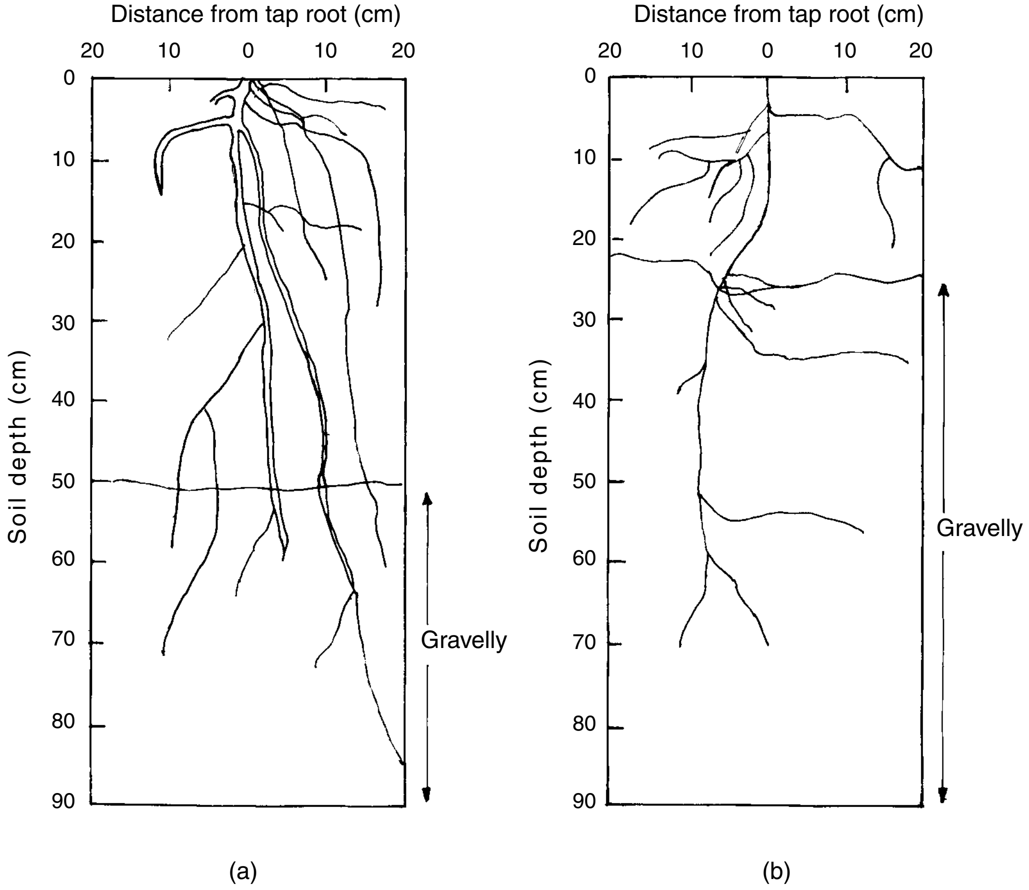

Figure 3. Spatial variation in root morphology and distribution of *Crotalaria ochroleuca* at 17 weeks after planting in Alabata, a derived savanna zone of south-western Nigeria: soil profiles with diffuse gravel at (a) > 50 cm depth; and (b) about 30 cm depth.

growth was similarly restricted (Figure 6b). Rooting depth for *C. ochroleuca* ranged between 37 and 50 cm in the NGS. *Centrosema pascuorum* roots (soil profiles not shown) at the NGS were restricted at 40 cm depth in two soil profiles and 50 cm in one.

Primary roots appeared thicker than the observed diameter in the DS (Figure 7). The mean rooting depth of 82 cm for the various legumes in the DS was significantly ($P < 0.001$) higher than mean rooting depth of 38.5 cm observed for the legumes in the NGS ($LSD_{0.05} = 10.22$). There were no significant differences between any paired root lengths obtained using computer software after scanning (Kirchhof and Pendar 1993) the mapped roots (Figures 2–7) of legumes in either the DS or NGS. Thus, the legumes had similar root distribution potential at each site. The legumes in DS had root lengths ranging from 1861 mm (*C. ochroleuca*) to 834 mm (*P. phaseoloides*) whereas the range at NGS was 939 mm (*C. cajan*) — 1277 mm (*C. pascuorum*). All legumes grown in the DS had root lengths similar to that of *C. odorata* (551 mm). However, root lengths of *C. ochroleuca* (1861 mm) and *I. cylindrica* (244 mm) at the site differed significantly ($P = 0.05$). Root lengths per unit area of profile wall ranged from 0.16 mm/cm^2 (*I. cylindrica*) to 0.58 mm/cm^2 (*C. ochroleuca*) in south-western Nigeria.

Light penetration, soil temperature and water potential

Soil surfaces with maize residue only (bare surface) received 93% incident light (Table 2). This was significantly higher than the light received under any of the legume canopies ($P < 0.001$).

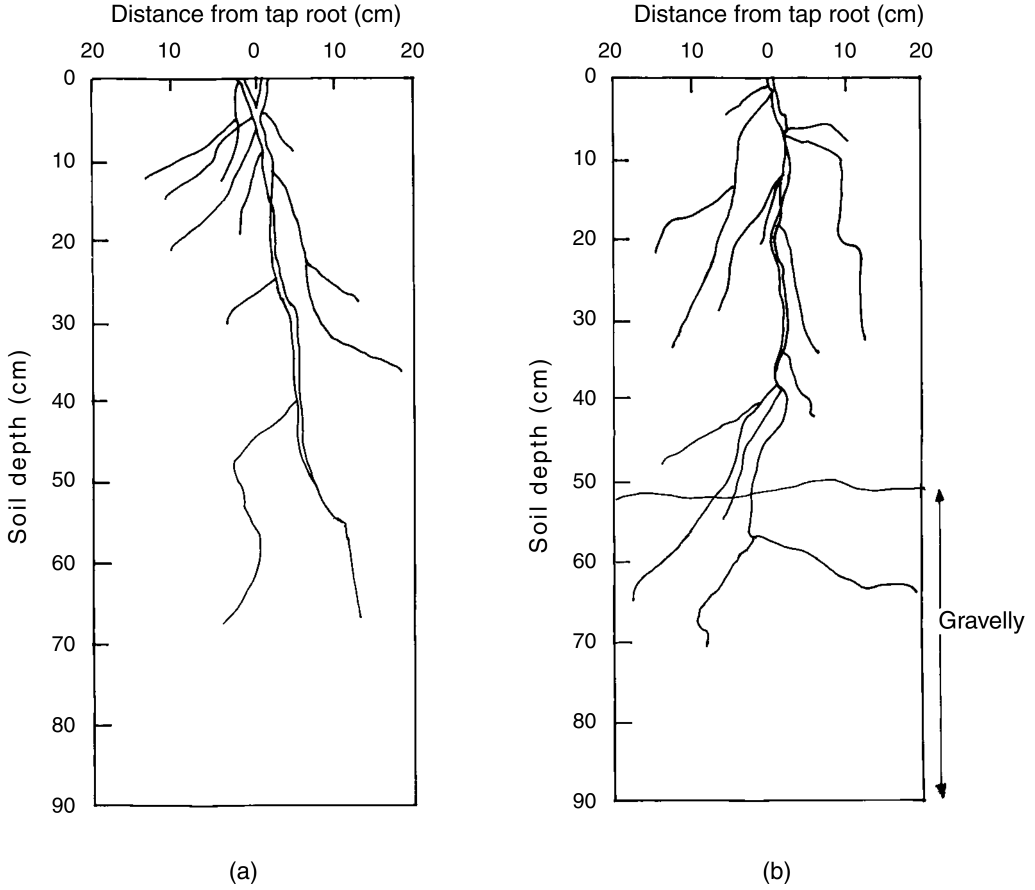

Figure 4. Spatial variation in root morphology and distribution of *Mucuna pruriens* (black) at 17 weeks after planting in Alabata, a derived savanna zone of south-western Nigeria; soil profile without gravel (a) and (b) a gravelly (below 50 cm depth) soil profile.

The amount of light which passed through the canopy of *C. pascuorum* was higher than that of any other legume ($P < 0.01$), except *C. ochroleuca*. In addition, more light passed through *C. ochroleuca* than through *M. pruriens* (black) and *P. phaseoloides* ($P = 0.02$).

Surface soil temperature (Figure 8) was significantly related to high penetration (coefficient of determination, $r^2 = 0.64$, $P = 0.03$, $n = 9$). The overall means (a range of 25.8°C for natural fallow *C. odorata* to 30.2°C for *C. pascuorum*) during the period of measurement indicated that soil temperature was significantly higher in *C. pascuorum* plots than in *C. odorata* (natural fallow) and *P. phaseoloides* plots ($P < 0.04$). Soil temperature was higher under *C. ochroleuca* than under *C. odorata* ($P = 0.02$).

Soil water potential during the period of measurement in the *C. pascuorum* plot was significantly lower than in any other plot ($P < 0.02$), except the *P. phaseoloides* plot (Figure 9). *Crotalaria ochroleuca* also had a significantly lower potential than *C. cajan*, *M. pruriens* and *C. odorata*. Generally, significant differences ($P = 0.05$) in soil water potential were observed between the highest and the least values (Figure 9). At 15 cm depth, there were significant differences in soil water potential for all measurements except at 142 days after planting (DAP). At 168 DAP, only the soil water potential of *C. ochroleuca* and *M. utilis* were significantly different at 15 cm depth (Figure 9).

Significant differences in soil water potential at 30 cm depth were observed between 142 and 155 DAP except on 147 DAP. Thereafter, significant differences were observed only at 168 DAP between *C. pascuorum* and each of *C. ochroleuca*, *C. odorata* and *M. utilis* (Figure 9).

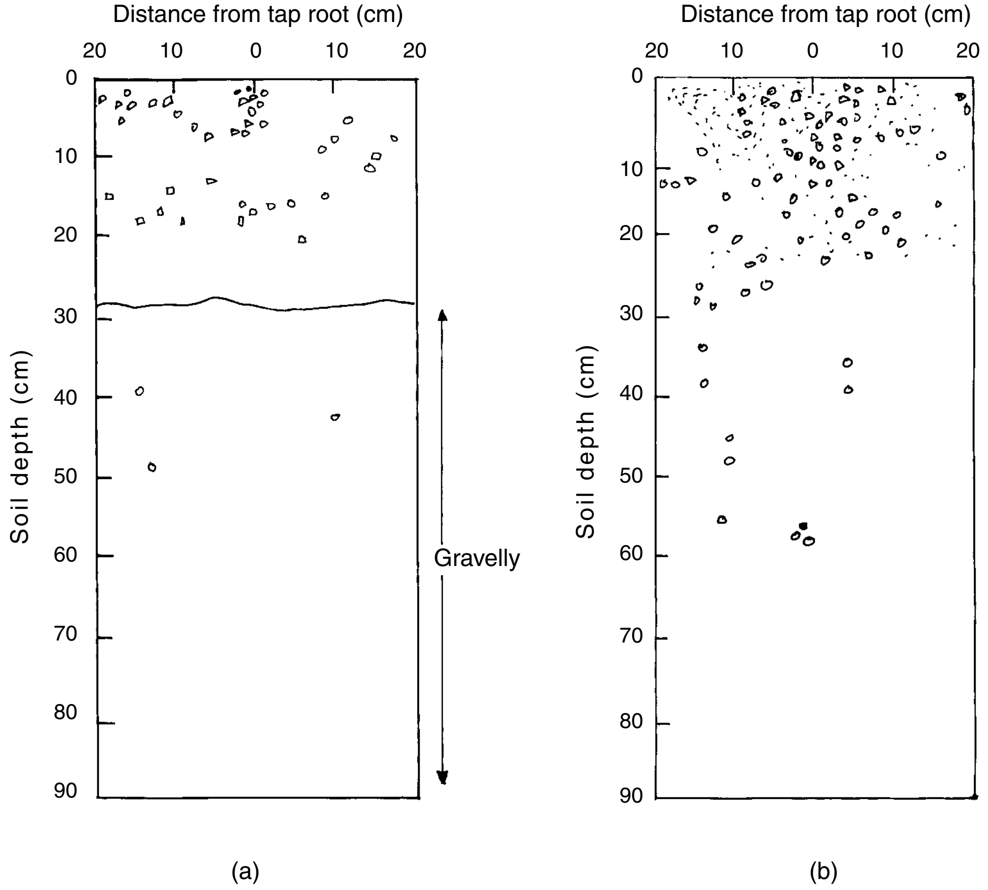

Figure 5. Spatial variation in root morphology and distribution of (a) *I. cylindrica* impeded by gravel; and (b) *C. odorata* without gravelly impediment at 17 weeks after planting in Alabata, a derived savanna zone of south-western Nigeria.

Volumetric surface soil water content was less than 10% at this time, and soil water potential was influenced more by ambient temperature (macroclimatic effects) than by species. Soil water potential at 15 cm depth was significantly lower than at 30 cm depth in each of the legume plots, and the natural fallow ($P < 0.01$), except in the *M. pruriens* (black) plot where both depths had similar potential.

Discussion

Root morphology and distribution

Desirable growth characteristics of forage or pasture legumes (Humphreys 1991; Tarawali *et al.* 1999; Muhr *et al.* 1999a; Peters *et al.* 2000) such as dry matter productivity, persistence in the dry season or ability to overcome drought, forage regeneration and high nutritive values depend on the ability of their roots to extract nutrients and water from the soil. This is a function of root growth which was restricted in both the DS and NGS (Figures 2–7), with the physical constraint in the NGS being more severe than in the DS.

The fertility of coarse-textured soil (Table 1) is inherently low, and this is pronounced in the tropics where leaching by high intensity rainfall contributes to loss of nutrients from the rooting depth of most plants (Jackson 1989; Humphreys 1991). Therefore, a plant with deep-rooting characteristics has the potential to recycle soil nutrients better than a shallow-rooted plant in the tropics. *Cajanus cajan* and *L. purpureus* were the only species which had root growth beyond 90 cm in the DS (Table 2; Figures 2 and 7). Both still showed a tendency for deep rooting (Figure 7) in soil profiles that could be dug up to

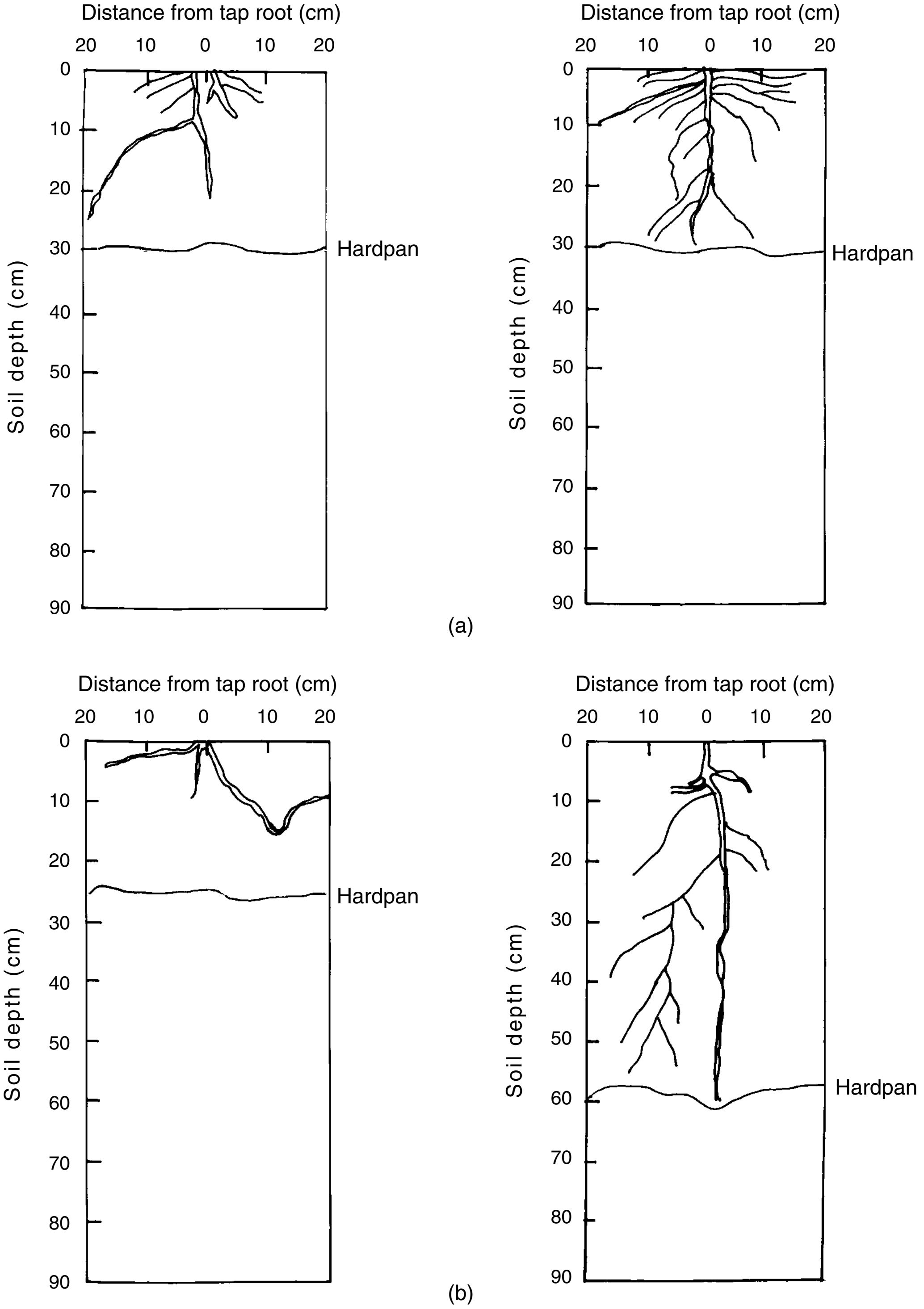

Figure 6. Spatial variation in root morphology and distribution of two plants each of (a) *Mucuna pruriens* (white); and (b) *Cajanus cajan* at 18 weeks after planting in Kasuwan Mangani, a northern Guinean savanna zone of northern Nigeria. Hardpan restrictions were encountered from 25 to 60 cm in various soil profiles.

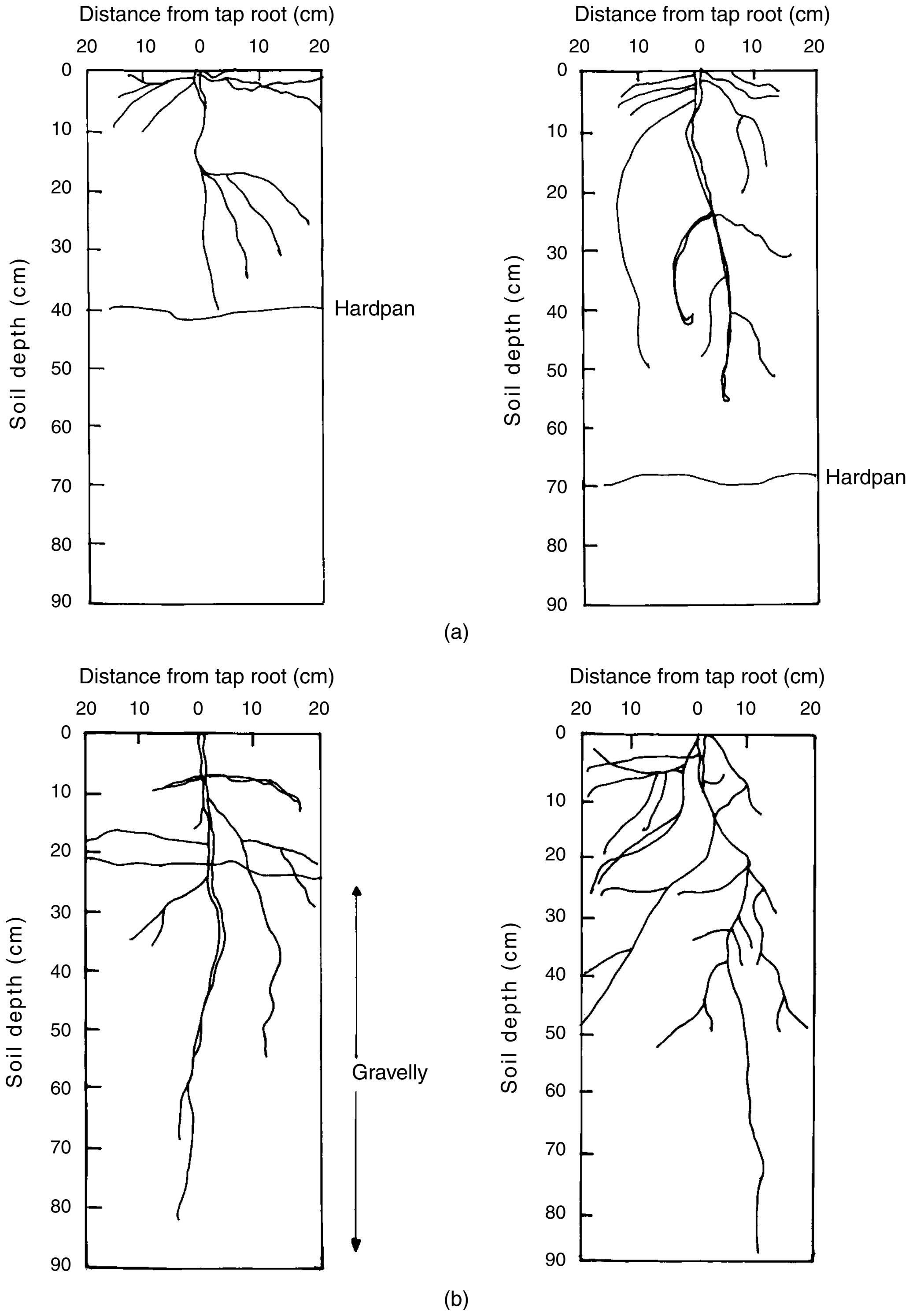

Figure 7. Spatial variation in root morphology and distribution of *L. purpureus* in (a) the northern Guinean; and (b) the derived savannas of Nigeria as influenced by hardpan and gravel.

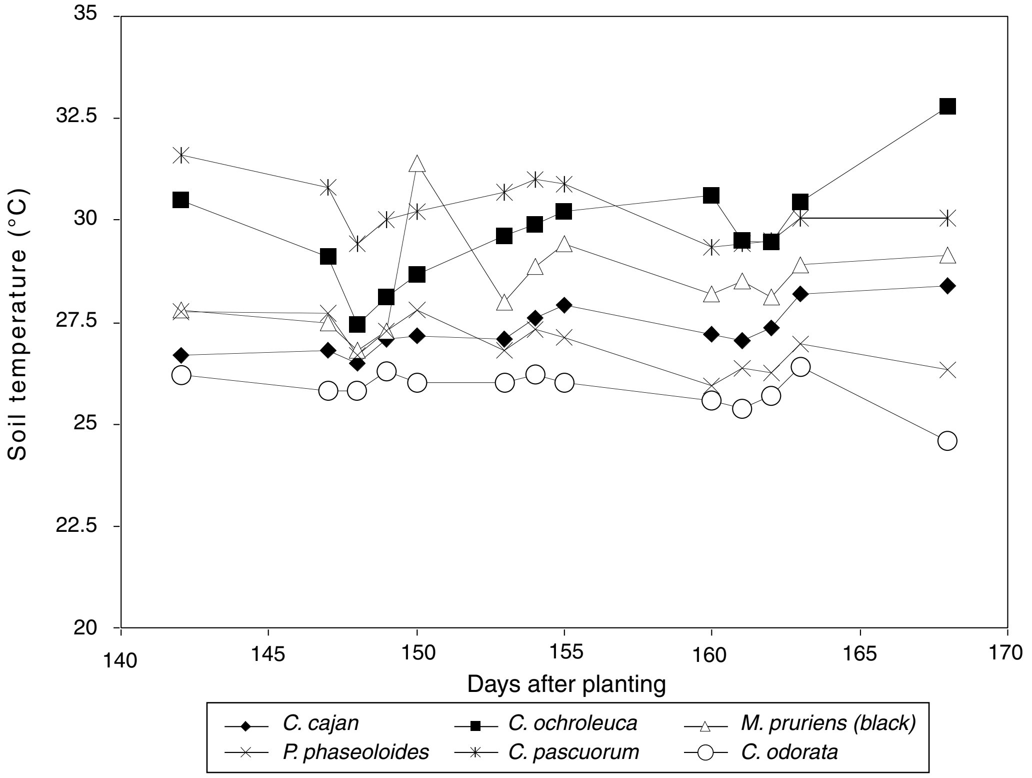

Figure 8. Surface soil (5 cm depth) temperature under different leguminous cover crops and natural fallow (*C. odorata*) in 1994 at Alabata, near Ibadan, south-western Nigeria.

60 cm depth at the NGS site. Nutrient recycling by deep-rooted plants to enhance growth of shallow-rooted plants is a principle in the practice of alley farming in which the foliage of the shrub or woody component which is the deep-rooted plant is fed to animals (Kang *et al.* 1999). The application of this concept is feasible in growing mixtures of pasture legumes in the savanna region (Humphreys 1991; Peters *et al.* 2000). The rooting depths in this study (Table 2; Figures 2–7) show that this objective can be achieved with the herbaceous or shrub forage legumes when intercropping a shallow-rooted main crop.

The root morphology and rooting depth data indicated that root distribution beyond 50 cm depth was higher in the DS than the NGS (Figures 2–7). However, total root lengths per profile were similar among the legumes because the legumes maximised the use of available soil volume for rooting. The lack of significant differences among the root lengths arose because the overall root length in the whole profile rather that root length per soil horizon was considered. Spatial variation existed both in the vertical and horizontal scale as indicated by the differences in root growth of the same species at the same location or the same species at different locations (Figures 2–7). This was irrespective of whether the legumes were shrubs or creeping herbaceous legumes. In effect, for the legumes to play an effective role in farming systems, consideration should be given to soil conditions for their own establishment too. Root densities usually vary inversely with soil depth, and the highest density is found in the topsoil.

In the DS, roots of the natural fallow species (*C. odorata* and *I. cylindrica*) were found at less than 60 cm depth, and grew more laterally than vertically (Figure 5). It appears from this habit that the natural fallow tended to exploit the topsoil without an attempt to venture into the subsoil with poorer characteristics. This implies that the effects of leguminous cover crops may be more pronounced in the subsoil than topsoil when compared with natural fallow. Most studies which compared the effects of natural fallow and

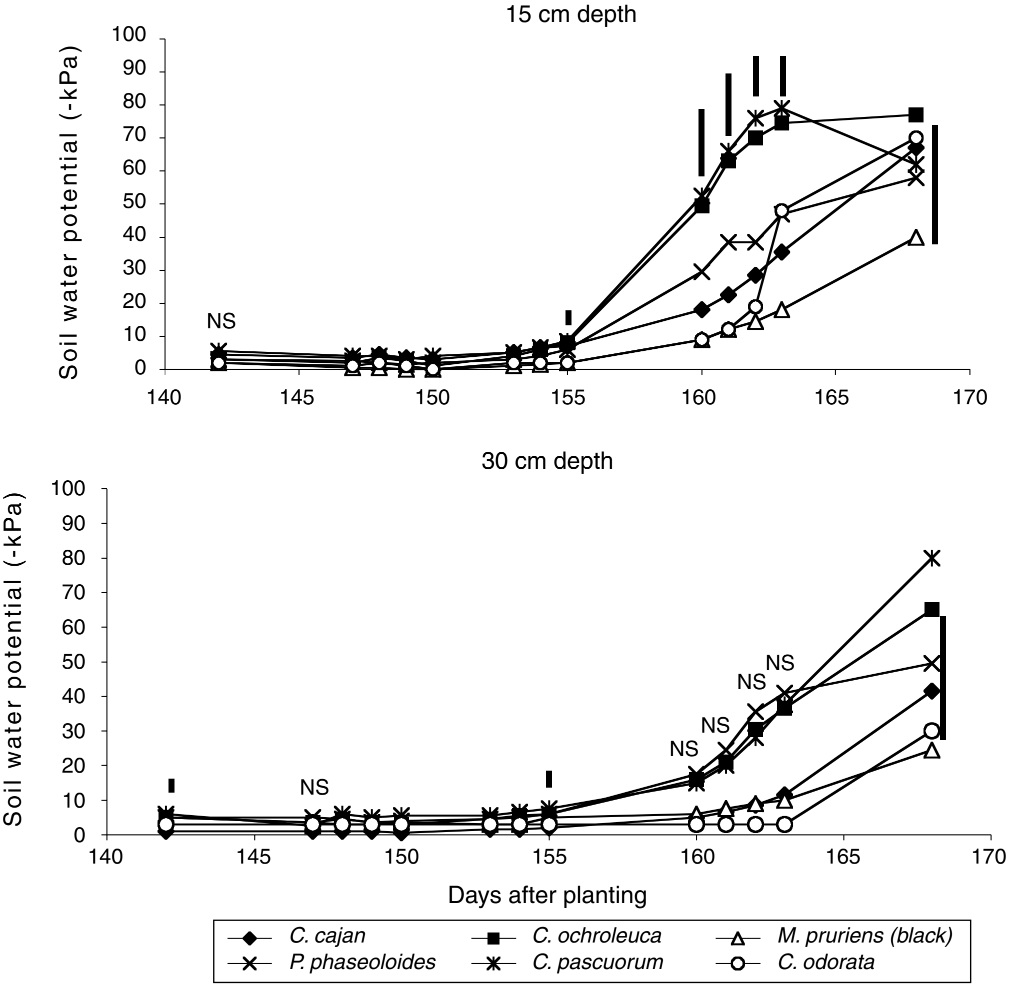

Figure 9. Soil water potentials at 15 and 30 cm depths under different leguminous cover crops and natural fallow (*C. odorata*) in 1994 at Alabata, near Ibadan, south-western Nigeria (vertical bars = $LSD_{0.05}$).

planted leguminous fallow have considered changes in the topsoil only, and usually observed no significant differences between the fallow systems (*e.g.* Kang *et al.*1997; Salako *et al.* 1999). Hulugalle and Lal (1986a) reported that root penetration by soybean and cowpea was significantly affected by a compacted gravel layer at 30 cm depth in south-western Nigeria, and soybean roots penetrated deeper in the absence of gravel but presence of a high (43–94 cm depth) water table. In spite of the gravel content of the soil, a *C. cajan*-maize rotation enhanced maize root growth under no tillage (Hulugalle and Lal 1986b). Adeoye and Mohamed-Saleem (1990) found that ridging or subsoiling would be required for the amelioration of the impedance to root growth caused by hardpans in the NGS.

Light penetration, soil temperature and water potential

The light penetration data (Table 2) suggest that, at maturity, the forage legumes covered the soil effectively. If 95% light interception is used as a critical value (Humphreys 1991), the data also suggest that *C. ochroleuca* and *C. pascuorum* were the only species which did not use available sunlight maximally. Maximum light interception is desirable only in areas with adequate soil moisture replenishment in relation to evapotranspiration. Apart from the dry spells which occur during the rainy season in the savanna regions (Jackson 1989), the coarse-textured topsoil (Table 1) does not retain a substantial amount of water unless wetted frequently. Tarawali *et al.*

(1995) reported that dry matter and seed yields of *C. pascuorum* were reduced by frequent cutting to feed animals in the NGS.

Effective soil coverage is also an advantage in soil conservation. However, this also has implications for shading of the main crop, and intercrops should be introduced into cropping systems only when antagonistic tendencies toward the main crop can be avoided. It may be easier to manipulate the spacing of legumes such as *C. pascuorum* and *C. ochroleuca* to the advantage of intercropping than legumes such as *M pruriens* and *P. phaseoloides*. Surface soil microclimate would differ substantially between the natural fallow, and *C. pascuorum* or *C. ochroleuca*.

Soil water potential was relatively low under *C. pascuorum* and *C. ochroleuca* and relatively high under *C. odorata* and *M. pruriens* (Figure 9). This was related to canopy coverage (Table 2), litter on the surface soil (visual observation) and water extraction by the plants. For instance, it appeared soil water potential was low under *C. pascuorum* and *C. ochroleuca* because their lower canopy coverage encouraged direct evaporation of the water from the soil surface. Conversely, *M. utilis* had matured by 140 DAP or 20 WAP with substantial litter on the soil surface (visual observation) and this would reduce evapotranspiration as it would require water sparingly to sustain itself while the litter prevented direct evaporation by sunlight. *Cajanus cajan*, a shrub (Figure 2) which was still growing actively during this period, maintained an intermediate suction because it was deep rooting (Figure 2) and had adequate canopy coverage (Table 2).

Soil water potential at 15 cm was lower than at 30 cm depth during this period because the surface soil was drier, and there was bound to be an upward movement of water by this time. However, the large amount of sand (Table 1) in this soil would probably make upward movement negligible. Furthermore, soil water potential was less than –10 kPa (a theoretical soil water potential for soil water content at field capacity in sandy soils) from 155 DAP upward at 15 cm depth but this was not generally so at 30 cm until 168 DAP (Figure 9). This suggested that soil water content was higher in the subsoil and only deep rooting legumes could explore it for an extended period (>1 month) after the cessation of rainfall. This would be enhanced if such legumes were perennials. *Cajanus cajan* and *P. phaseoloides* were suitable as forage legumes in terms of rooting depth, canopy coverage (Table 2) and maintenance of intermediate soil water potential at the onset of the dry season (Figure 9). Intercropped broad-leaved legumes could limit water availability to the main crop in the savanna zone by high evapotranspiration.

Total root length of legumes was not linearly related to soil water suction (positive values which translate to negative of soil water potential were used) and temperature. Furthermore, the relationship between surface soil temperature and light penetration through the canopy, and the data on soil water potential in this study agree with the finding of Muchow (1985) that the proportion of radiation intercepted at solar noon in relation to canopy density by some legumes could influence soil water deficits. Surface soil temperature, light under canopies and soil moisture influence pasture regrowth through their effects on seed germination (Jutzi and Nosberger 1984; Keating and Mott 1987; Humphreys 1991). There are light-sensitive seeds or seeds that require softening before germination.

Based on this study, *C. cajan*, *L. purpureus*, *M. pruriens* and *P. phaseoloides* are recommended as forage legumes in the savanna because of their deep (>60 cm rooting depth of *C. odorata*) rooting characteristics and their large canopy coverage which enhanced interception of sunlight for growth. *Cajanus cajan* and *P. phaseoloides* showed a strong tendency for survival in the dry season. The criteria used are, however, not exhaustive because a desirable characteristic for a particular utilisation may not be desirable for another. The rooting depth of the legumes indicated that they would be more useful in nutrient cycling than natural fallow of the same age in the savanna region.

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