Chapter 6

Spatial rooting pattern of gliricidia, pigeonpea and maize and distribution of soil nitrogen and phosphorus in a simultaneous intercropping system

Abstract

Competition for below-ground resources between trees and crops growing simultaneously in the same space is high when the fine roots of the trees grow in the same strata as the crops. Such competition in general will decrease the nutrient use efficiency by the crop. In order to understand the belowground distribution of roots of maize, pigeonpea and gliricidia roots in a simultaneous intercropping system, root studies were conducted in three cropping systems, namely: sole maize, pigeonpea - maize intercropping and gliricidia - maize intercropping. Pigeonpea and maize root development was monitored at 21, 42 and 63 days after planting. Also soil mineral N and Olsen P were assessed along the soil profile to 200 cm depth and compared between treatments.

Maize roots developed faster than those of pigeonpea during the first 42 days after planting and there was little overlapping of maize and pigeonpea roots. However, at 63 days an extensive overlap of pigeonpea and maize roots was observed. In pigeonpea -maize intercropping system, maize roots density declined from 0.45 cm cm^{-3} in the surface soil to 0.03 cm cm^{-3} at 130 cm, whereas density of pigeonpea roots varied from 0.35 cm cm^{-3} in the surface soil to 0.04 cm cm^{-3} at 200 cm depth. In gliricidia - maize intercropping, maize had the highest root density (averaging 1.02 cm cm^{-3} for both sites) in the top 0-40 cm soil layer. Gliricidia had an average of 0.38 cm cm^{-3} in the top 0-40 cm soil layer (for both sites) and of 0.65 cm cm^{-3} in the 40-100 cm soil layer. In gliricidia – maize intercropping, mineral N was increased by 44 kg ha^{-1} and 34 kg ha^{-1} in the 0-100 cm soil layer whereas Olsen P decreased by 32 kg ha^{-1} in the entire 0-200 cm soil profile. Because maize had more roots growing within 0-40 cm soil layer than gliricidia it could possibly take more advantage of the nutrients from the applied gliricidia prunings.

6.1 Introduction

The success of the simultaneous intercropping of trees with crops in agroforestry system is dependent on the temporal and spatial complementarity of resource capture by trees and crops (Cannell *et al.,* 1996). Competitive interactions for resources (light, water and mineral elements) between the trees and crops in alley cropping in different practices have been intensively studied during the last decade (Akonde *et al*., 1996; Itimu, 1997; Jose *et al*., 2000a, 2000b; Miller and Pallardy, 2001; Livesley *et al*., 2002; Radersma, 2002). In simultaneous agroforestry systems, pruning management of the aboveground part of the trees reduces the aboveground competition. Uptake of the nutrient resource by the trees within the rooting zone of the annual crops may reduce the nutrient recovery by the crop but what portion of the nutrients released from added plant material is taken up by the trees usually is unknown.

Competition for belowground resources is high when the agroforestry trees have most of the fine roots confined in the same strata as the associated food crop (Ruhigwa *et al*., 1992; Schroth, 1995, 1999; Akinnifesi *et al*., 1999a), and low when the trees have few roots growing in the rooting horizon of the crops and more of their roots growing in the deeper soil layers. The trees that have their roots growing below the crop rooting horizon are beneficial in the sense that they can intercept leached nutrients *i.e*. act as a "safety-net" (Rowe *et al*., 1999) and also capture nutrients from deep layers (Young, 1997). It has been suggested that competition between the trees and crops for belowground resources could be minimized by (1) deep ploughing so that the tree roots growing in the top soil layer are sloughed off (Kowar and Radder, 1994), (2) root pruning along the tree hedges (Fernandes *et al*., 1993) (3) selecting trees that have most of their roots growing below the crops rooting horizon (Akinnifesi *et al*., 1999a), (4) shoot pruning reducing competition for water and nutrients (Miller and Pallardy, 2001), and (5) by growing crops in ridges and trees in furrows.

Smallholder farmers in Southern Malawi intercrop pigeonpea in gliricidia-maize simultaneous intercropping system (Makumba and Akinnifesi, 2000). Trees are grown in furrows and maize and pigeonpea on ridges. This practice further increases the tree and crops population in a small piece of land. Competition for aboveground and belowground resources could be exacerbated in such dense multiple intercropping agroforestry systems, reducing yield and nutrient use efficiency by the associated crop. Gliricidia simultaneous intercropping is a variant of hedgerow intercropping with maize. In gliricidia simultaneous intercropping with maize, tree rows are closely spaced at 1.5 m apart with two maize rows in the alleys, 0.375 m from the tree rows. By contrast, in alley cropping the tree rows are commonly spaced at 4-5 m apart.

The current knowledge on spatial root distribution of trees and crops in simultaneous agroforestry systems is based on studies in alley cropping systems where the tree rows are spaced at 4-5 m apart (Hauser, 1993; Scroth *et al*, 1995; Itimu, 1997; Ahiou *et al*., 1999; Tossah *et al*., 1999; Vanlauwe *et al*., 2002). In gliricidia simultaneous intercropping with maize there are two maize rows in the alleys between the tree rows and each maize row is 37.5 cm away from a tree row. The information obtained from alley cropping system with wide alleys 4-5 m may not easily be extrapolated to a system with 1.50 m wide alleys. Since root characteristics of trees change with crop husbandry, tree management and site conditions (Schroth, 1999; Akinnifesi *et al*., 1995; van Noordwijk *et al*., 1991), it is essential to understand the rooting patterns of trees and crops in gliricidia simultaneous intercropping with maize and pigeonpea.

The premise of the current study was that the multiple intercropping agroforestry systems as practiced in Malawi will face competition for belowground resources, but that the practice of growing trees in furrows and crops on ridges minimizes such competition. This study was undertaken to (1) increase our understanding of pigeonpea and maize root development during the growing period in a mixed cropping system; (2) understand the vertical and horizontal root distribution of gliricidia, pigeonpea and maize in a simultaneous cropping system; (3) understand the effect of gliricidia and pigeonpea on mineral N and Olsen P down the soil profile.

6.2 Materials and Methods

The studies were conducted in two fields, MZ12 and MZ21, both at Makoka Agricultural Research Station. The sites have been described in Chapter 2. The experiment at MZ12 was established in December 1992 and has been designed for long-term biophysical studies. Because of this, we could not carry out ‘destructive studies’. As a compromise, we excavated trenches for root studies and profile soil characterization in one replicate only. We selected only treatments without inorganic

N and P fertilizer for our root studies at MZ12. The experiment at MZ21 was established in December 1995, and most of our 'destructive' root studies were conducted in this experiment because the aboveground biophysical studies at this site were phased out in 1999.

6.2.1 Aboveground plant development and dry-matter yields

Maize grain and dry matter yields were measured every season at harvest in May. Pigeonpea was harvested in August and the yield of pigeonpea and weight of pods were determined at the time of harvest whereas the tree biomass was determined at the time of incorporation of the organic materials. Gliricidia biomass yield (prunings and wood) were measured each time the trees were pruned (August, October, December and February). In 2001-02 season maize and pigeonpea plant heights were recorded at 21, 42 and 63 days after maize planting.

6.2.2 Methods of root studies

Three methods were deployed to assess the rooting patterns of the trees and crops (see also chapter 2):

(1) root core sampling at various growth stages of maize,
(2) root mapping on the profile wall, and
(3) excavation of structural roots and tap roots of the central and border trees.

6.2.2.1 Root sampling and determination of root length of maize and pigeonpea

Maize and pigeonpea root development was monitored in the maize-pigeonpea intercropping during the maize growing period at 21, 42 and 63 days after planting (DAP), corresponding to the periods of fast growing, vegetative growth and the start of anthesis, respectively. Root samples were taken by driving a core sampler (100 cm^3 volume) into the soil on the ridge at lateral distances of 10, 20, 30 and 40 cm from the maize plant (Fig. 6.1), and at 10 cm intervals to 60 cm depth at 21 DAP, and to 70 cm depth at 42 DAP. At 63 DAP, soil cores were collected from the soil profile wall (refer to Section 2.5 for full description).

The soil cores were washed through a set of sieves (2 mm, 1 mm and 0.30 mm). The fine roots (<2 mm) collected were treated with 17% acetic acid and kept in a refrigerator at 4 ^{o}C while waiting for sorting and root length measuring.

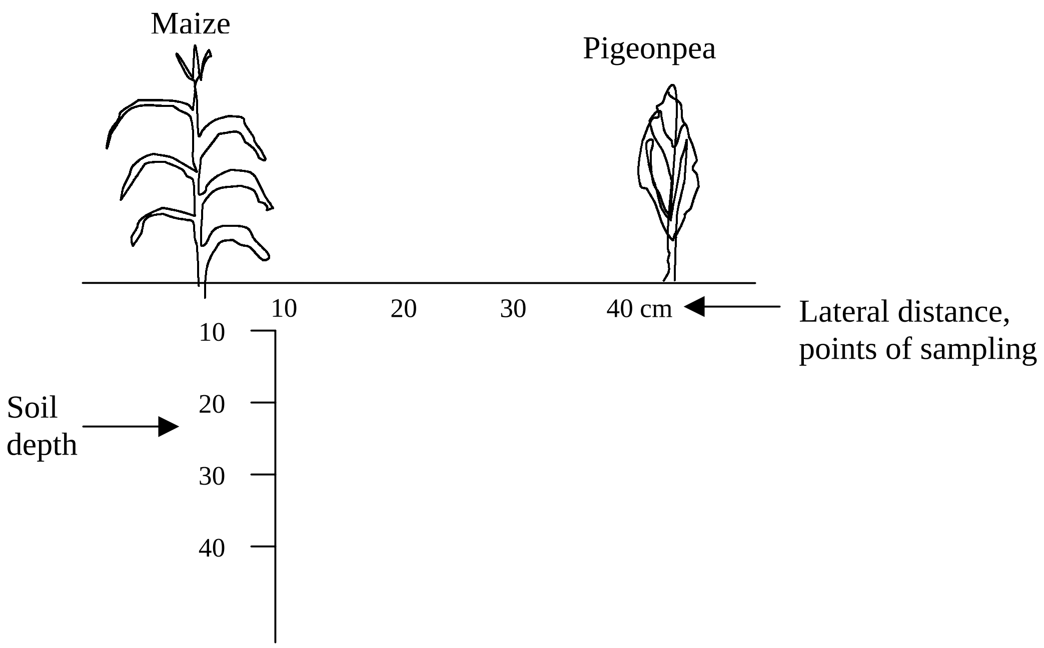

Fig. 6.1. Schematic diagram showing the points of root core sampling on the ridge in maize/pigeonpea intercropping system

The fine roots (<2 mm) were sorted under a 10 times magnifying glass. The roots of different species were differentiated based on their color, pliability and branching characteristics. The dead roots were distinguished by their darkish-gray coloration of the cortex. The method described by Tenant (1975) was followed to determine the root lengths. A 0.5 x 0.5 cm grid paper was placed beneath a one-liter beaker filled with about 2 cm film of water on which the roots were floated. The set up was illuminated with a table reading light. Counts of the intercepts of the roots with the vertical and horizontal grid lines were made with the aid of the magnifying glass and a hand tally counter. Complete counts were converted to length measurements using the Tennant (1975) modified formula:

Root length (R) (cm) = $^{11}/_{14}$ * number of intercepts (N) * grid unit (cm). Eq. 6.1

The root length was then divided by the volume of the core to obtain the root length density (cm dm^{-3}).

6.2.2.2 Root quantification of maize and gliricidia on the soil profile wall

At MZ12, (eight weeks after maize planting in 2001) trenches measuring 2.5 m x 1.0 m x 3.0 m were dug in sole maize (Sole-Maize) and gliricidia-maize simultaneous intercropping (Gs-Maize) perpendicular to the tree and maize rows. The trenches were dug in one replicate and were not replicated in the other replicates. A grid frame was pushed onto the profile wall covering at least four maize rows and two tree rows.

At MZ21 four trenches were excavated in the following cropping systems (1) Sole-Maize, (2) maize intercropping with pigeonpea (Pea-Maize), (3) gliricidia - maize simultaneous intercropping (Gs-Maize) and (4) gliricidia - pigeonpea - maize (Gs-Pea-Maize) simultaneous intercropping. The trenches were dug in March 2002, each measuring 2.5 m x 1.0 m x 2.0 m. The trenches were dug parallel to the ridges, 40 cm away from the tree row and 5 cm from the maize/pigeonpea row. A grid frame was fixed into the profile wall covering three maize planting hills and three pigeonpea planting hills in between the maize planting hills (gliricidia trees were in a furrow behind pigeonpea plants, see Fig. 2.4). At both sites replication was done within the same trench for all the treatments hence will be referred to as pseudo-replicates (Vanlauwe *et al*., 2002). The roots were sampled within a distance of 50 cm starting from the tree row covering one row of maize for MZ12 or one maize planting hill for MZ21 at either side of the tree. The roots from the same row and depth locations from the two sides (left and right) of each tree row were averaged and were treated as a pseudo-replicate. At both sites depth 0 cm corresponds to the top of the ridge.

6.2.2.3 Excavating lateral structural roots of gliricidia

From the *net* plot (central trees) of MZ21 the roots of five trees were excavated to 200 cm depth exposing the taproot and all the primary roots (>5 mm). Diameter of taproot was measured before each branching point and primary roots branching from the taproot were counted. In a separate excavation, the spread and form of the lateral structural roots (>5 mm) were investigated. From the *border* of the plots (exterior) five trees were randomly selected and the roots growing in the surface 0-40 cm were excavated, exposing them to their full length and then the taproot was followed to 200 cm depth. The diameter of the primary roots was measured from the tree trunk or taproot to the tip at 10 cm intervals. The number of secondary roots growing from the primary roots was also recorded and the measurements were repeated for the taproot. The branching angle of the primary roots for the interior and border trees were measured.

6.2.3 Assessment of mineral N and Olsen P along the soil profile

After root mapping (Section 6.2.2.2), soil samples for determination of mineral N, were collected along the profile wall at 20 cm depth intervals to 300 cm at MZ12 and at 10 cm depth intervals to 200 cm at MZ21. The grid frame was used to demarcate the sampling points and samples were collected from each 10 x 10 cm square grids. The grid frame was divided into three segments. Each grid segment had 8 (10 x 10 cm) square grids per soil depth, whose samples were bulked together to make one bulk sample representing a pseudo-replicate. The bulked samples were subdivided into two; one sub-sample was dried and analyzed for Olsen P and the other was placed in a fridge at 4 ^{o}C prior to mineral N analysis.

6.3 Results

6.3.1 Aboveground plant development and dry-matter yields

During the first 42 days after planting (DAP) the height of maize and pigeonpea plants increased by 5.76 cm day^{-1} and 4.52 cm day^{-1} respectively (Table 6.1). At 63 DAP the increases in height of pigeonpea (3.67 cm day^{-1}) was higher than that of maize (0.95 cm day^{-1}). At 63 days after planting the maize had started flowering. At MZ12 maize dry-matter yields were 5.6 and 5.4 times higher in Gs-Maize than in Sole-Maize in 2000-01 and 2001-02 respectively (Table 6.2). At MZ21 total maize dry-matter yield for maize in the four systems increased in the order: Gs-Pea-Maize > Gs-Maize > Pea-Maize > Sole-Maize (Table 6.3). In Gs-Pea-Maize, maize dry-matter yields were 1.4 and 0.2 t ha^{-1} higher than in Gs-Maize in 2000-01 and 2001-02, respectively. Pigeonpea yields were lower in Gs-Pea-Maize than in Pea-Maize; pigeonpea yields in Gs-Pea-Maize were reduced by 18% in 2000-2001 and by 11% in 2001-2002. Gliricidia biomass yield was about a ton ha^{-1} higher in Gs-Pea-Maize than in Gs-Maize.

6.3.2. Vertical and lateral fine root distribution

6.3.2.1 Maize and pigeonpea

At 21 days after planting (DAP) maize root length density was highest (220 cm dm^{-3}) in the upper 10 cm, close to the maize hill (10 cm away) and decreased with distance away from the maize plant and also with soil depth (Fig. 6.2, Appendix 6.1). A similar trend was obtained for pigeonpea roots. Pigeonpea had most of its roots growing close to the pigeonpea plant; root length density sharply declined with distance away from the plant. No maize roots were found close to the pigeonpea plant at lateral distance of 40 cm and soil depth of 0-20 cm and vice versa. A few maize roots occurred at the soil depth 30-60 cm at lateral distance of 40 cm close to pigeonpea planting hill.

At 42 DAP maize root length density had increased to 780 cm dm^{-3} in the soil surface (10, 10 cm) and to 90 cm dm^{-3} at a depth of 70 cm (10, 70 cm) (Fig. 6.2). Maize root length density was still low in the surface soil close to the pigeonpea plant (40, 20 cm). Pigeonpea root length density was 80 cm dm^{-3} in the surface soil close to the maize plant (10, 10 cm), and increased to 120 cm dm^{-3} at a depth of 30-40 cm just below the maize plants (10, 30-40 cm). Maize and pigeonpea roots substantially overlapped between 20 and 30 cm lateral distance.

At 63 DAP the maize root length density had increased to 1080 cm dm^{-3} and pigeonpea root length density to 890 cm dm^{-3} in the soil surface close to each plant (Fig. 6.3, Appendix 6.2). Pigeonpea roots grew up to 200 cm deep whereas no maize roots grew deeper than 130 cm. In the subsoil between 30 and 80 cm and at a distance of just 10 cm from the maize plant, pigeonpea root length density ranged between 270 and 360 cm dm^{-3}.

6.3.2.2 Maize and gliricidia

Maize root length density was significantly ($P = 0.05$) higher in the topsoil between 0 and 40 cm than at greater depths at both sites, MZ12 and MZ 21 (Fig. 6.4, Appendix 6.3). The maize root length density declined with increasing depth down the soil profile. The root length density of sole maize was higher than that of maize intercropped with gliricidia and the decline of root length density with depth was less in sole maize than in maize intercropped with gliricidia. Gliricidia had significantly ($P = 0.05$) lower root length density between 0 and 20 cm (ranging between 30 and 460 cm dm^{-3}) than between 20 and 90 cm at MZ12 and than between 20 and 170 cm at MZ21. Gliricidia root length density remained high up to 120 cm, but decreased below that depth.

Table 6.1. Maize and pigeonpea plant height (cm) measured at various times during the growing period.

	Maize	Pigeonpea
Plant height (cm)		
21 DAS[a]	69 a	55 a
42 DAS	190 a	150 b
63 DAS	210 a	227 a
Mean increase in plant height (cm/day)[b]		
0-21 DAS[a]	3.29	2.62
21-42 DAS	5.76	4.52
42-63 DAS	0.95	3.67

[a]Values followed by the same letter in a row are not significantly different at P=0.05 by DMRT. [b]The increase in plant heights are calculated from the plant heights

Table 6.2 Aboveground maize grain and gliricidia biomass yields (t/ha) at MZ12 in 2000-2001 and 2001-2002.

	Maize		Gliricidia	Total biomass
	Grain	Stover	Biomass[a]	
2000-2001				
Sole maize	0.8	1.0	-	1.9
Gs-Maize	5.0	5.6	10.0	20.6
2001-2002				
Sole-Maize	0.7	0.9	-	1.6
Gs-Maize	4.3	4.7	9.2	18.2

[a]Biomass yield for gliricidia is the sum of leaf and wood biomass

Table 6.3. Maize and pigeonpea grain and biomass yields, and gliricidia biomass yield (t/ha) in cropping systems at MZ21 in 2000-2001 and 2001-2002.

	Maize		Pigeonpeas		Gliricidia	Total biomass
	Grain	Stover	Peas	Biomass[a]	Biomass[a]	
2000-2001						
Sole maize	0.9	1.0	-	-	-	1.9
Pea-Maize	2.7	3.2	0.6	5.9	-	12.4
Gs-Maize	3.1	3.3	-	-	9.3	15.7
Gs-Pea-Maize	3.7	4.1	0.5	4.8	10.3	23.4
2001-2002						
Sole maize	1.0	1.1	-	-	-	2.1
Pea-Maize	1.6	1.9	0.44	4.7	-	8.6
Gs-Maize	3.0	3.1	-	-	8.4	14.5
Gs-Pea-Maize	3.1	3.2	0.39	4.1	9.1	19.9

[a]Biomass is the sum of leaves and wood

6.3.2.3 Lateral spread of structural roots of gliricidia

Structural root (>5 mm) diameters differed considerably between the central trees (net plot) and the boundary trees (Fig. 6.5, Table 6.4). The roots spreading outside the tree plot from the boundary trees were bigger (35.2 mm diameter) than the central trees (26.9 mm diameter). The roots of the central trees tapered from 26.9 cm to 6.6 cm within an average distance of 80 cm from the tree trunk whereas the average diameter of roots from the boundary trees at the same root length was 21.4 mm. The boundary trees spread as far as 400 cm away from the tree trunk whereas the central trees had a maximum spread of 110 cm (Figs. 6.6 and 6.7, Table 6.4). The angle between the primary root and taproot show whether the roots spread outwards or go deep into the soil. The smaller the angle the more the roots go deep into the soil. The angle between taproot and the primary roots of the central trees (49^{o}) was smaller than the roots spreading outside the tree plot ($89\ ^{o}$).

Table 6.4. Summary of lateral root spread between 0 and 40 cm soil layer

	Collar root diameter (mm)	Root length (cm)	Branching angle (cm)
Trees from the central plot			
Mean	64	59	49
Maximum	80	110	80
Minimum	55	30	20
Trees at the border of the plot			
Mean	77	266	86
Maximum	82	400	115
Minimum	72	190	70

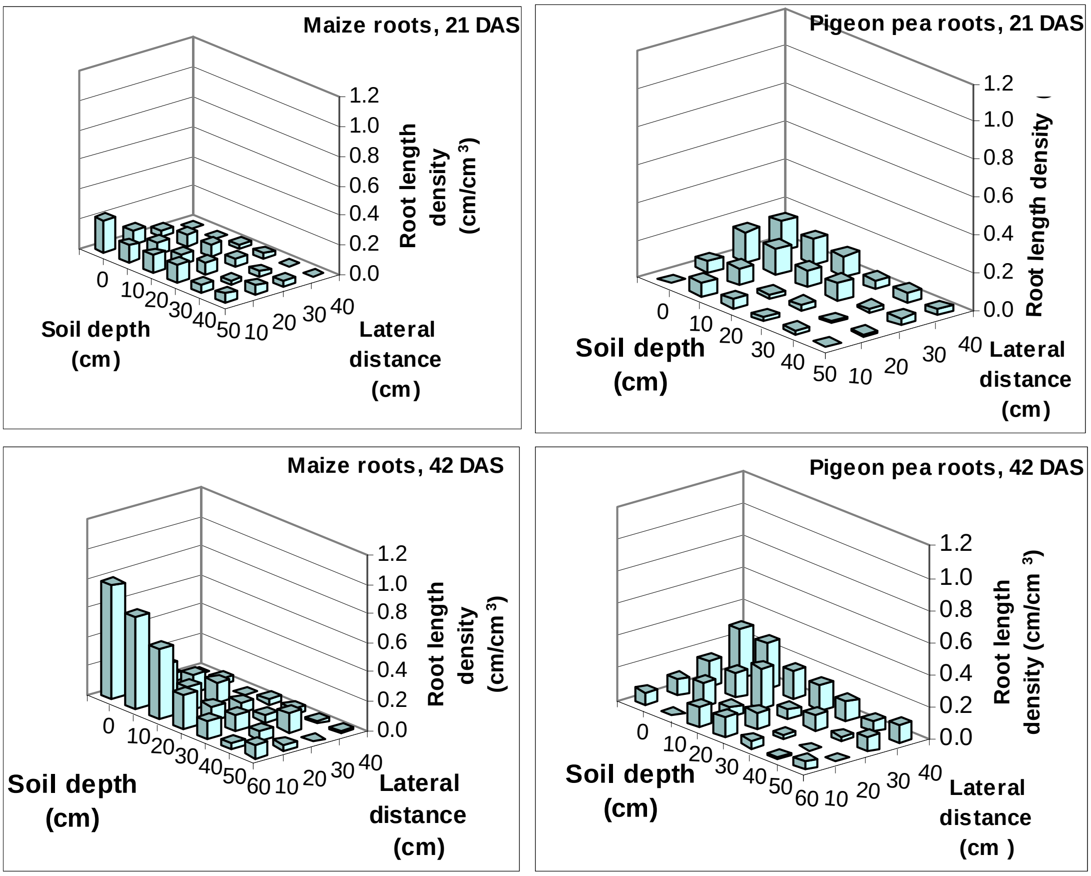

Fig. 6.2. MZ21, maize and pigeonpea fine (• 2mm diameter) root densities (cm cm^{-3}) in a maize-pigeonpea intercropping system measured at 21 and 42 DAP.

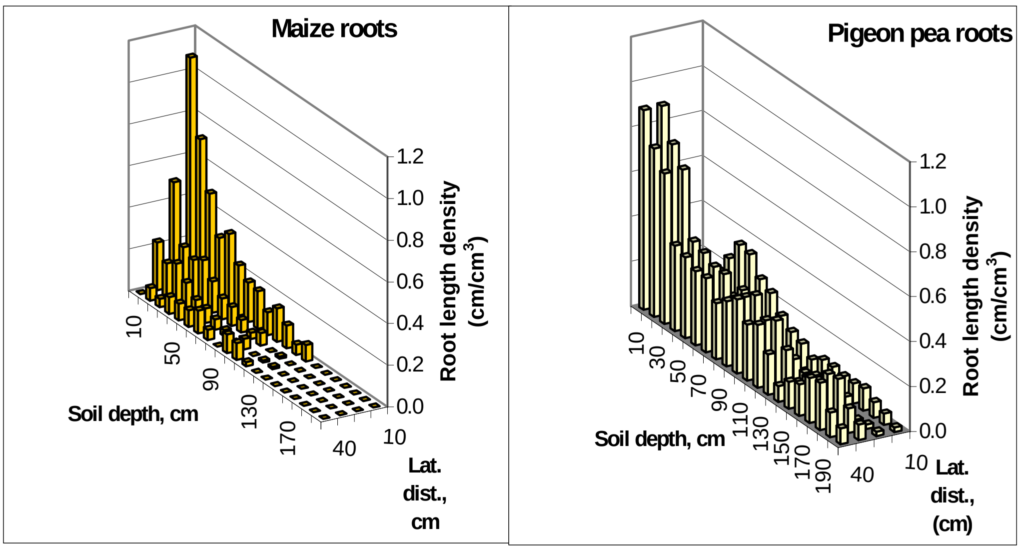

Fig. 6.3. MZ21, vertical and lateral root distribution of maize and pigeonpea in a maize-pigeonpea intercropping system at 63 days after planting. L.S.D (5%): Lat. Dist. = 0.0042 and depth = 0.0094 for maize roots and Lat. Dist. = 0.0058 and depth = 0.0129 for pigeonpea roots (the L.S.Ds are for log (n+1) transformed data (Gomez and Gomez, 1984, Vanlauwe, *et al.*, 2002).

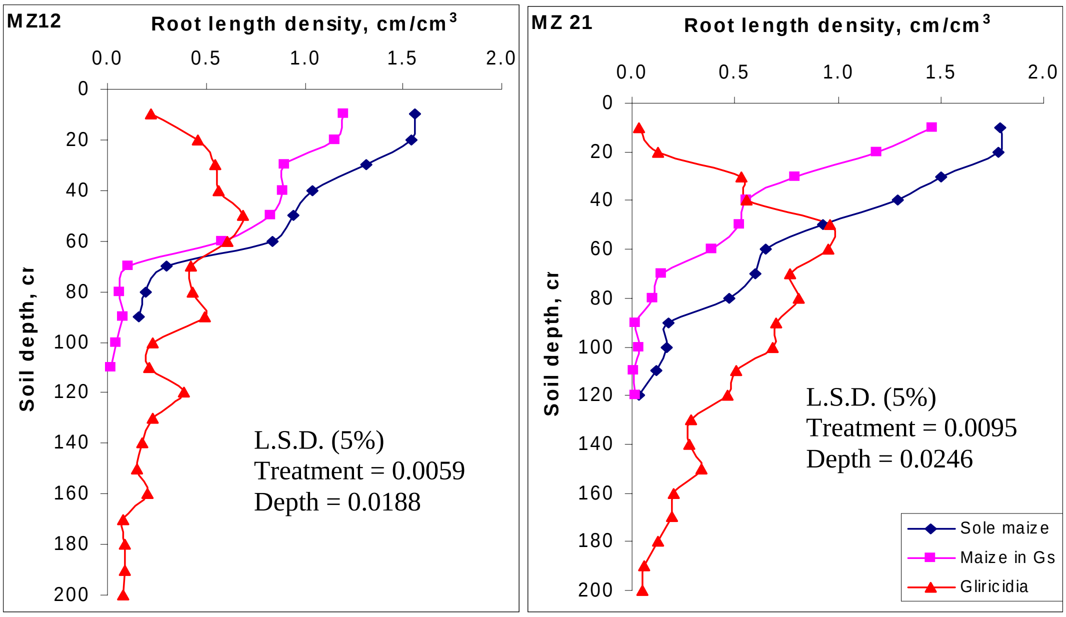

Fig. 6.4. Maize and gliricidia fine roots (<2 mm diameter) distribution along the soil profile wall at MZ12 and MZ 21. L.S.D.s are for Log10 (n+1) transformed root length density data. 'Maize in Gs' is the root length density of maize intercropped with gliricidia.

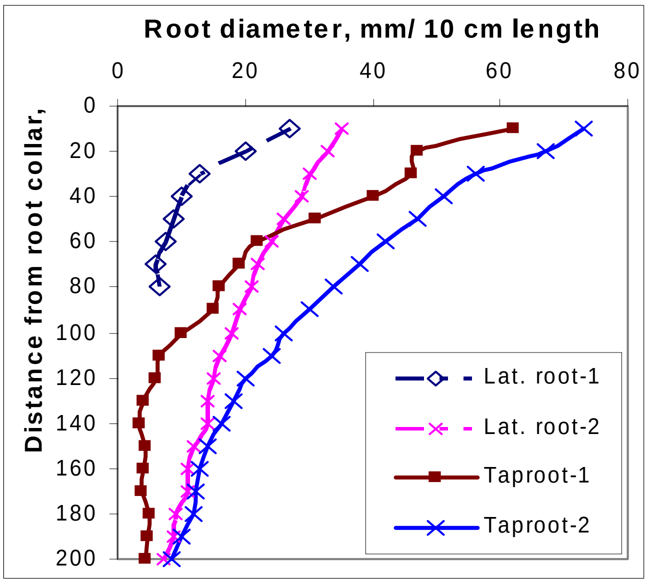

Fig. 6.5. Taproot diameter per 10 cm depth and structural root diameter per 10 cm distance intervals away from the tree trunk for the border and interior trees in a Gs-Maize simultaneous intercropping system. Lat. root-1 and Taproot-1 are lateral and tap roots for the central trees and Lat. root-2 and Taproot-2 are for the border trees

Fig. 6.6 Lateral spread of gliricidia structural roots for the trees growing in the net plot (in the text referred to as central trees)

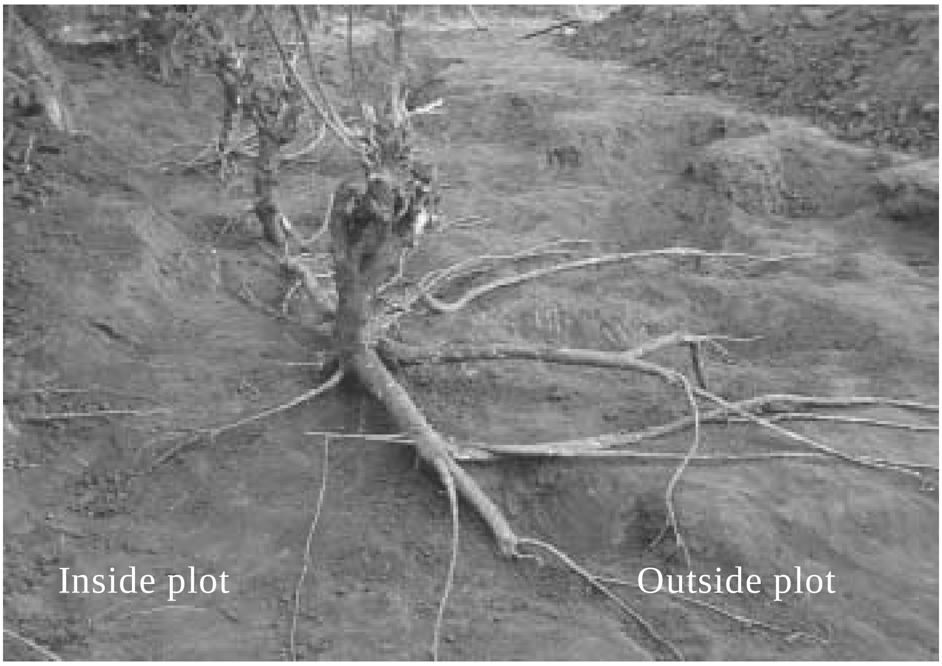

Fig. 6.7 Lateral spread and structural form of gliricidia structural roots for the trees in the border of the tree plot

6.3.3 Distribution of mineral N and Olsen P down the soil profile

6.3.3.1 Mineral N

Figure 6.8 depicts soil mineral N down the soil profile in the two and four cropping systems of MZ12 and MZ21 respectively. In Sole-Maize, less mineral N was found in 0-100 cm than in the subsoil (100-200 cm) of MZ12; the difference in soil mineral N between Sole-Maize and Gs-Maize was big in the layers between 0 and 100 cm, but not in the deeper soil from 100-200 cm (Table 6.5). In almost all soil layers to 200 cm, mineral N was higher in Gs-Maize than in Sole-Maize. At MZ21, amounts of soil mineral N in the upper 50 cm were significantly (P = 0.05) larger in Pea-Maize, Gs-Maize, Gs-Pea-Maize than in Sole-Maize.

Table 6.5. Amounts of soil mineral N (kg N ha^{-1}) in 0-100, 100-200 and 0-200 cm soil layers, in Sole-Maize, Pea-Maize, Gs-Maize and Gs-Pea-Maize cropping systems at MZ12 and MZ21.

	0-100 cm	100-200 cm	0-200 cm
MZ12			
Total mineral N			
Sole-Maize	65	125	175
Gs-Maize	108	141	232
N increase over Sole-Maize			
Gs-Maize	44	16	57
At MZ21			
Total mineral N			
Sole maize	112	138	235
Pea-Maize	154	122	265
Gs-Maize	146	86	222
Gs-Pea-Maize	136	114	237
N increase relative to Sole-Maize			
Pea-Maize	42	-16	30
Gs-Maize	34	-52	-13
Gs-Pea -Maize	24	-24	2

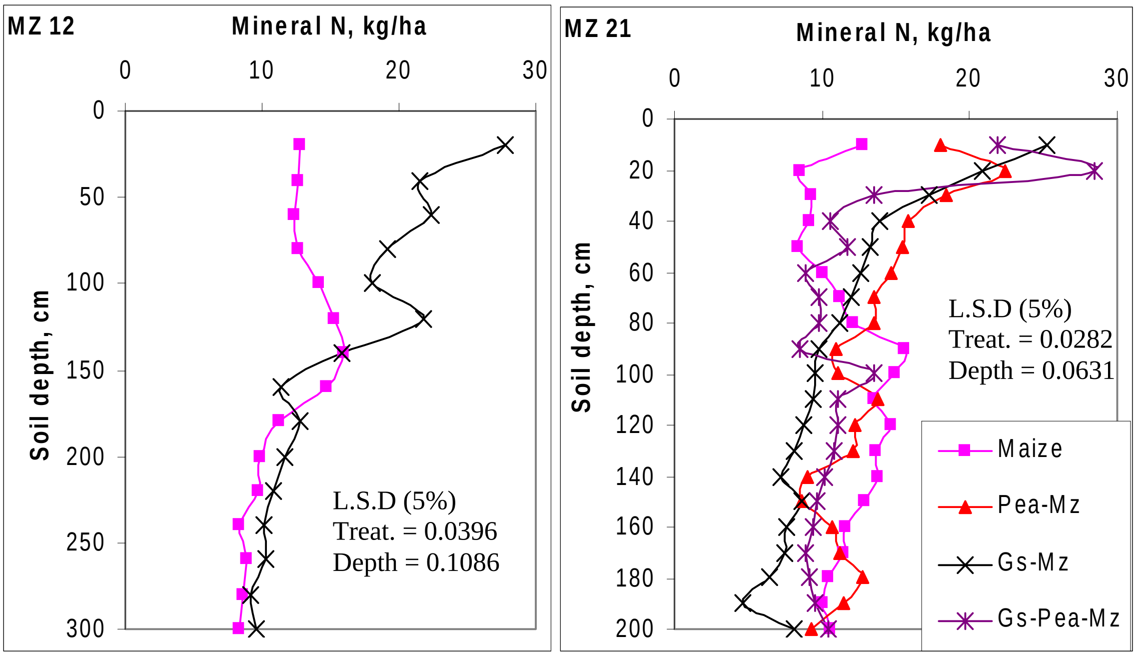

Fig. 6.8. Mineral N (kg ha^{-1}) along the soil profile at MZ12 and MZ21. The L.S.D.'s at 5% level are for log10 (n+1) transformed mineral N (Gomez and Gomez, 1984).

6.3.3.2 Olsen P

At MZ12 Olsen P was higher than at MZ21. At MZ12 Olsen P was higher in Gs-Maize than in Sole-Maize in the 0-40 cm soil layer, but lower at depths below 80 cm (Fig. 6.9). Olsen P was 9 kg ha^{-1} higher in Gs-Maize than in Sole-Maize in the upper 0-100 cm, but was 53 kg ha^{-1} lower in the subsoil (100-200 cm) (Table 6.6). At MZ21, Olsen P was lower in Gs-Maize than that in Sole-Maize and Pea-Maize. At both sites, Olsen P level decreased with depth but more in the Gs-Maize than in Sole-Maize.

6.4 Discussion

6.4.1 Roots

The root length densities of maize in our study are comparable to the root length densities reported by other authors (van Noordwijk and Brouwer, 1991; Scroth and Zech, 1995) for maize planted close to trees. In a senna-maize alley cropping system maize roots density ranged from 1050 cm dm^{-3} at 75-150 cm from the hedgerow to

1490 cm dm^{-3} at 450-525 cm from the hedgerow in the top 15 cm soil (Livesley *et al.*, 2000).

Growth rate of pigeonpea roots was lower than that of maize roots during the early growing stages. The fast root and shoot development of maize during the early growing stages (up to 42 DAP) gave maize a competitive advantage over pigeonpea for belowground and aboveground resources. After 63 DAP, pigeonpea roots and maize roots overlapped considerably within the 0-60 cm soil layer. This overlap could suggest possible competition for soil resources between maize and pigeonpea during the second half of the maize growing period. Akinnifesi *et al*. (1999b) also found that 93% of the pigeonpea roots occurred between 0-60 cm soil layer where most of maize roots occurred. However, the data of maize yield indicate that maize was a stronger competitor than pigeonpea, as maize yields were higher in Pea-Maize than in Sole-Maize (see Chapter 5 and Table 6.3).

The low root density of gliricidia between 0-30 cm depth (Appendix 6.3) could be due to (1) roots were sloughed off when tilling (Kowar and Radder, 1994), (2) planting of maize on ridges and the trees in the furrows already brought tree roots to start growing at 30 cm below the ridge top, and (3) low spread of structural roots of the central trees in the surface (0-40 cm). Schroth and Zech (1995) also found that maize had higher root density in the surface soil than the gliricidia trees. At MZ21 prior to cropping in 2000-2001 season we realigned the ridges in the gliricidia plots, tree roots might have been cut when breaking the ridges thus reducing the tree roots within the ridge. By contrast, gliricidia had many roots extending to deeper soil layers that were not used by maize roots. In gliricidia-maize alley cropping at Chitedze, Malawi, Itimu, (1997) found root length density of maize of 940 cm dm^{-3} in the top 0-20 cm and of 130 cm dm^{-3} at 80 cm depth, whereas gliricidia had between 400 and 500 cm dm^{-3} in the top 0-20 cm and more than 500 cm dm^{-3} below 40 cm. In alley cropping of *Grevillea robusta* and maize, Livesley *et al*. (2000) found that maize had 60% of its roots in the upper 30 cm and as little as 20% below 90 cm. The roots of *Grevillea robusta* and *Senna spectabilis* decreased in the upper 60 cm during the cropping season.

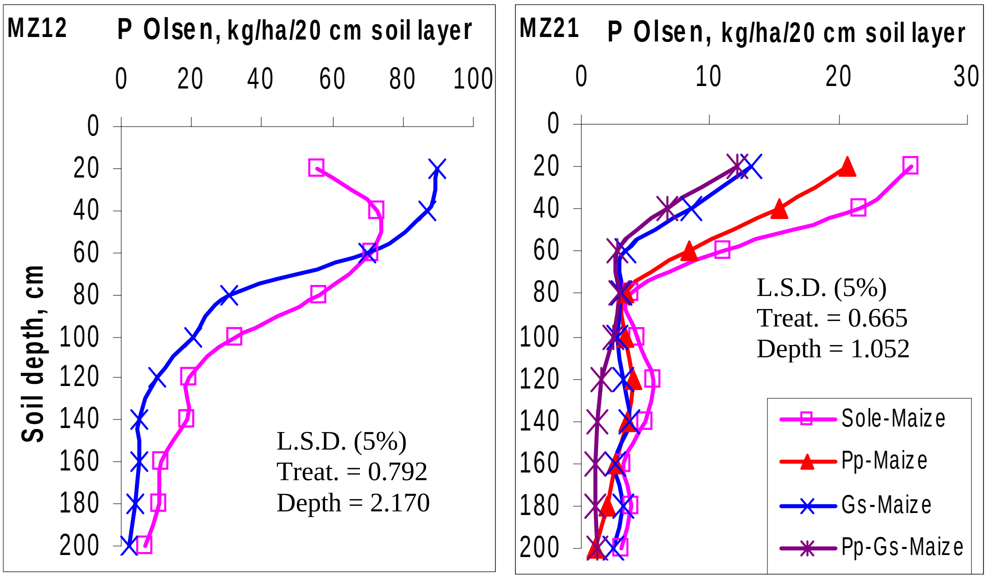

Fig. 6.9. Effect of different land use systems on Olsen P distribution along the soil profile. At site MZ12, sole-maize and gliricidia-maize were compared, and at MZ21 Sole-Maize, Gs-maize, Pea-maize and Gs-Pea-Maize

Table 6.6. Amounts of Olsen P (kg/ha) in 0-100, 100-200 and 0-1200 cm soil layers, in Sole-Maize, Pea-Maize, Gs-Maize and Gs-Pea-Maize systems at MZ12 and MZ21

	0-100 cm	100-200 cm	0-200 cm
At MZ12			
Total Olsen-P			
Sole-Maize	288	100	356
Gs-Maize	297	47	324
P increase relative to Sole-Maize			
Gs-Maize	9	-53	-32
At MZ21			
Total Olsen-P			
Sole-Maize	67	23	87
Pea-Maize	65	25	87
Gs-Maize	44	23	66
Gs-Pea-Maize	45	12	55
P increase relative to the control			
Pea-Maize	-2	2	0
Gs-Maize	-23	0	-21
Gs-Pea-Maize	-22	-11	-32

The structural roots from the border trees grew up to 4 m into the neighboring plots without trees. This suggests that gliricidia can also obtain nutrients from the neighboring plots. Some trees *e.g. Senna siamea* can have their lateral roots growing horizontally to feed in the neighboring plots 9 m away (Rao *et al*., 1993). Because of the possible competition between the neighboring trees and also with the crop, the central trees develop fewer structural roots in the upper 0-40 cm and increase down the profile (Schroth and Zech, 1995; Livesley *et al*., 2000).

6.4.2 Aboveground dry-matter yields

The dry-matter yield of maize was higher in Gs-Pea-Maize than in Gs-Maize and in Sole-Maize, whereas the pigeonpea total biomass yield was higher in Pea-Maize than in Gs-Pea-Maize (Table 6.3). The decline of pigeonpea yield in Gs-Pea-Maize is an indicator that pigeonpea suffers from competition in this system. Initially, maize was growing faster than pigeonpeas and thereby benefited more from the applied nutrients than the intercropped pigeonpea. This follows also from the low root length density of pigeonpea during the first 42 DAP. Although pigeonpea root length density had increased at 63 DAS it might have been too late to recover sufficient nutrients from the soil. The larger maize dry-matter and gliricidia biomass yields in Gs-Pea-Maize relative to Gs-Maize may be due to the extra organic N added via pigeonpea leaves. The decomposing pigeonpea roots apparently also contributed substantially to the amount of mineral N in the soil as reflected by high subsoil mineral N in Pea-Maize in February 2002 (see Chapter 5, Appendix 5.4). Our results suggest that competition by trees was stronger on the secondary crop, pigeonpea, than on the primary crop, maize.

6.4.3 Mineral N

The distribution pattern with depth of soil mineral N reflects in part the distribution of roots in the various systems, and the application of gliricidia prunings and pigeonpea crop residues. The low subsoil N in Gs-Maize indicates that gliricidia recycles N leached N from the surface soil. Hartemink *et al*. (2000) found that after 10 months of establishment of sesbania in an improved fallow, the trees decreased subsoil N (100-200 cm depth) by 45 kg ha^{-1} in an Oxisol and 52 kg ha^{-1} in Alfisol in Kenya. In another study Jama *et al*. (1998) reported a reduction of 150 to 200 kg NO_3 ha^{-1} in the top 200 cm soil in calliandra and sesbania planted fallows. These results confirm that gliricidia trees recycle mineral N leached to soil depth beyond the maize rooting horizon. The increase in subsoil mineral N in pigeonpea compared to gliricidia might be due to N mineralized from the decomposing pigeonpea roots. Pigeonpea had up to 330 cm dm^{-3} root length density at 200 cm depth, which upon decomposition might have contributed to increased amounts of mineral N in the soil. In this system pigeonpea is grown as an annual crop and each year a new crop is planted. This implies that the roots of the previous crop decompose and release nutrients within the soil profile every year. Gathumbi *et al*. (2002) also found larger amounts of mineral N in the subsoil in a pigeonpea fallow than in a sesbania fallow.

6.4.4 Olsen P

At MZ12, the increase of Olsen P between 0-100 cm and decrease in the subsoil (100-200 cm) in Gs-Maize compared to Sole-Maize suggests that the trees 'pumped' P from the deeper soils layers through their roots and 'deposited' it in the surface soil via the prunings and root turnover. Increases in Olsen P in 0-100 cm soil layer are smaller than the decreases in 100-200 cm soil layer probably because of the P removal via maize harvesting and some removal via the tree wood.

The occurrence of pigeonpea and gliricidia roots below the maize rooting zone, up to 200 cm depth, and the decrease of N and P in the deeper soil layer confirm the idea of capturing and pumping leached nutrients from the deeper soils to the topsoil (van Noordwijk *et al.*, 1996; Rowe *et al*, 1999).

6.5 Conclusions

In pigeonpea with maize intercropping system, maize was initially a stronger competitor for nutrients in the surface soil than pigeonpea because maize had a faster root development and a higher rate of shoot growth than pigeonpea. Since the tree prunings were applied at 15 cm within the ridge, maize had greater chances of benefiting from the released nutrients than gliricidia.

Gliricidia root density was low within the ridge (0-30 cm) ranging between 30 to 460 cm dm^{-3} but increased to 690 cm dm^{-3} at MZ12 and 960 cm dm^{-3} at MZ21 at a depth of 40-50 cm. The low root density within 0-30 cm and the high maize yielding in gliricidia-maize intercropping system indicates that gliricidia did not compete much with maize for underground resources. Furthermore, the increase of gliricidia root density below the maize rooting zone till the greater depths enabled the trees: (1) to intercept the nutrients leached beyond the rooting zone and (2) to explore ‘native’ soil nutrients from great depth and to pump these nutrients to the surface. After 9 to 10 years of ‘pumping’ P from the deeper soils the tree plots have shown a decrease of Olsen P (32 kg ha^{-1}) in the 0-200 cm soil profile.

Yields of pigeonpea were low. Nevertheless, the farmers in addition to increased maize yield also have peas, which are an important source of protein. Intercropping of pigeonpea in gliricidia-maize simultaneous intercropping system increases the organic N applied via the biomass. Pigeonpea root turnover also supplies N in the subsoil. The slow growing pigeonpea faced more competition from gliricidia than from maize.

Appendices

Appendix 6.1. Pigeonpea and maize root length density (cm dm^{-3}) at 21 and 42 days after maize planting, measured along the ridge.

Treatment	Depth (cm)	Lateral distance from maize plant (cm) 10	20	30	40	Mean
21 days after planting						
Maize roots	10	220 a	100 a	40 c	0 d	*90*
	20	120 b	80 b	80 a	0 d	*70*
	30	120 b	70 bc	80 a	20 b	*70*
	40	120 b	80 b	50 b	30 a	*70*
	50	60 c	30 d	30 d	10 c	*30*
	60	60 c	60 c	40 c	10 c	*40*
	Mean	*120*	*70*	*50*	*10*	*40*
Pigeonpea roots	10	0 d	60 b	160 a	160 a	*100*
	20	70 a	90 a	140 a	130 b	*110*
	30	50 b	20 cd	90 b	110 c	*70*
	40	20 c	30 c	90 b	50 d	*50*
	50	20 c	10 d	20 d	50 d	*30*
	60	0 d	10 d	40 c	30 e	*20*
	Mean	*30*	*40*	*90*	*90*	*60*
42 days after planting						
Maize roots	10	780 a	160 b	60 cd	0 c	*250*
	20	630 b	250 a	120 b	40 a	*260*
	30	480 c	160 b	140 a	0 c	*200*
	40	230 d	100 c	70 c	40 a	*110*
	50	120 e	110 c	50 d	40 a	*80*
	60	40 f	60 d	130 ab	20 b	*60*
	70	90 e	40 e	0 e	20 b	*40*
	Mean	*270*	*120*	*0.09*	*30*	*120*
Pigeonpea roots	10	80 b	100 b	160 b	300 a	*160*
	20	10 d	150 a	150 b	280 a	*150*
	30	120 a	60 c	250 a	180 b	*150*
	40	130 a	100 b	60 d	160 b	*110*
	50	50 c	30 d	90 c	120 c	*70*
	60	10 d	0 e	30 e	70 d	*30*
	70	50 c	0 e	90 c	110 c	*60*
	Mean	*60*	*60*	*110*	*150*	*100*

In a column means followed by a common letter are not significantly different at 5% level by DMRT

Appendix 6.2. Maize and pigeonpea root length density (cm dm^{-3}) in relation to soil depth and lateral distance between maize and pigeonpea plant at 63 days after planting

Soil depth	Maize					Pigeonpea				
(cm)	10	20	30	40	*Mean*	10	20	30	40	*Mean*
0-10	1080	500	230	0	*450*	110	150	260	890	*350*
10-20	720	220	160	0	*280*	150	190	170	750	*310*
20-30	490	190	190	60	*230*	180	190	210	670	*310*
30-40	310	220	130	40	*180*	270	170	250	380	*270*
40-50	360	150	80	80	*170*	360	180	160	360	*260*
50-60	240	100	70	80	*120*	350	180	160	330	*260*
60-70	190	90	50	80	*100*	270	240	120	330	*240*
70-80	180	60	30	110	*100*	240	80	130	250	*180*
80-90	110	30	0	50	*50*	170	50	120	290	*160*
90-100	160	60	50	0	*70*	130	90	90	330	*130*
100-110	110	0	0	90	*50*	110	90	50	250	*120*
110-120	50	10	10	80	*40*	70	90	100	280	*140*
120-130	80		10	20	*30*	100	60	90	180	*110*
130-140						100	80	90	70	*80*
140-150						90	80	80	120	*90*
150-160						90	40	80	140	*90*
160-170						100	80	30	200	*100*
170-180						70	10	30	210	*80*
180-190						50	20	40	110	*60*
190-200						20	20	30	70	*40*
Mean	310	140	80	50	*140*	150	100	110	310	*170*

Appendix 6.3. Maize and gliricidia root length density (cm dm^{-3}) distribution along the soil profile in sole maize cropping and gliricidia-maize simultaneous intercropping systems at MZ12 and MZ21

Soil layer (cm)	MZ12			MZ21		
	Sole Maize	Intercropping		Sole Maize	Intercropping	
		Maize	Gs		Maize	Gs
0-10	1560 a	1200 a	220 gh	1790 a	1460 a	30 j
10-20	1540 a	1150 a	460 de	1780 a	1190 b	130 i
20-30	1310 b	900 b	550 c	1500 b	790 c	530 ef
30-40	1040 c	890 b	560 c	1290 b	560 c	560 e
40-50	940 cd	830 b	690 a	930 c	520 c	960 a
50-60	840 d	580 c	610 b	650 d	390 d	950 a
60-70	300 e	110 d	420 ef	600 d	140e	770 bc
70-80	190 f	60 de	430 ef	470 e	100e	810 b
80-90	160 f	80 de	490 d	180 f	20 f	700 c
90-100		40 e	230 g	170 f	30 f	680 d
100-110		20 f	210 gh	120 f	10 f	510 ef
110-120			390 f	30 g	20 f	460 f
120-130			230 g			290 g
130-140			180 h			280 g
140-150			150 h			340 g
150-160			200 gh			200 h
160- 170			80 i			190 h
170-180			90 i			130 i
180-190			90 i			60 j
190-200			80 i			50 j
Mean	880	530	320	790	440	430

Appendix 6.4. MZ21 mean diameter of taproot at various depths and of lateral roots diameter (mm) at various distances from gliricidia root collar

Distance from tree trunk (cm)	Taproot		Lateral roots	
	Central	Border	Central	Border
10	62	73	27	35
20	47	67	20	33
30	46	55	13	30
40	40	51	10	29
50	31	47	8.7	26
60	20	42	7.5	24
70	19	38	6.1	22
80	16	34	6.6	21
90	15	30		19
100	10	26		18
110	6.7	24		16
120	5.9	20		15
130	4.0	17		14
140	3.6	17		14
150	4.3	14		12
160	4.1	13		11
170	3.7	11		11
180	4.9	12		9.2
190	4.7	10		8.8
200	4.3	8.6		7.3