ROOT GROWTH AND DISTRIBUTION PATTERN IN *LEUCAENA LEUCOCEPHALA*, *GLIRICIDIA SEPIUM* AND *SENNA SIAMEA* IN THE HUMID LOWLANDS OF GHANA

AGRICULTURE

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ABSTRACT

Horizontal and vertical distribution of roots of one year old Leucaena eleucocephala, Gliricidia sepium and Senna siamea plants on field plots were studied using the skeleton (dry excavation) method. Root systems of the three species generally consisted of a strong downward growing tap root with laterals originating from the main root axis. In Leucaena and Senna, roots developed faster than shoots, and at the end of 9 weeks after sowing, mean root length shoot height ratios were 1.41 and 1.46 respectively. Total root biomass ranked in the order Senna > Gliricidia > Leucaena. The bulk (an average of about 81%) of the root biomass of all the three species are found in the top 15cm depth of the profile. Horizontal root spread varied from 98.2cm in Leucaena to 104.7cm in Senna. Active nodules were observed on the roots of Leucaena and Gliricidia but not Senna. The study concludes that the three species are likely to compete with agricultural crops for water and nutrients when grown together.

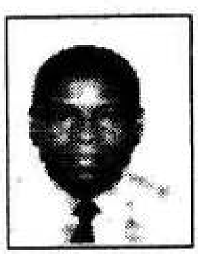
Keywords: *Agroforestry, root systems, root competition, Leucaena leucocephala, Gliricidia sepium and Senna siamea.*

INTRODUCTION

Agroforestry is a collective name for land-use systems that combine the cultivation of woody perenials (trees and shrubs) with food crops on the same land management unit either in spatial mixture or in temporal sequence (Lundgren and Raintree 1982). It combines the protective characteristics of forestry with the productive attributes of both forestry and agriculture. It is recognised as one of the ecologically most appropriate agricultural systems especially in the densely populated, ecologically degraded areas of the tropics where the environment is so vulnerable.

There are several agroforestry practices. Perhaps the best known and most widely researched over the last two decades is alley cropping. It is a system of farming in which arable crops are grown in the spaces between rows of planted trees which are pruned periodically during the cropping season to prevent shading, minimise intercrop competition, and provide green manure and mulch for the associated crops (Wilson and Kang, 1980). Alley cropping has been shown to be a stable alternative to shifting cultivation and modest soil fertility restoration and maintenance have been reported under the system (Kang et. al. 1984). Field experiments show that in alley cropped plots yields of cassava, maize and cowpeas can be maintained at a relatively high level (Gichuru and Kang, 1990).

Despite these reported successes, the spontane-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ous adoption expected by farmers is not being achieved, mainly because of the apprehension among farmers that trees in association with crops will compete strongly with crops for nutrients and moisture as well as space. Experimental results are available showing yield reduction due to alley cropping with certain woody species (Tropsoils 1987; Gichuru and Kang, 1990). This effect is partly blamed on root competition for nutrients and moisture.

A knowledge of rooting systems of trees is therefore crucial in the selection, design and management of agroforestry systems. It will ensure that multipurpose trees selected for agroforesty interventions are compatible and can utilise in harmony the above and below-ground resources over time with associated crops. It will permit researchers to find the best way of managing below-ground portions of hedgerow species to benefit the associated crop.

While the above ground interactions in alley cropping systems are well known, only little knowledge is available on below-ground interactions among hedgerow and food crop species due mainly to obvious difficulties in its study (Lal, 1991; Huck, 1983)

The present paper reports on the growth performance and the vertical and horizontal distribution of roots of one year old seedlings of Leucaena leucocephala, Gliriclidia sepium and Senna siamea.

MATERIALS AND METHODS

Study Site

The study was conducted on the Institute of Renewable Natural Resources' Research Farm at the University of Science and Technology, Kumasi, Ghana (Lat 06° 43'N), (Long 01°36'W) at an altitude of 278m. The average annual rainfall is 1250mm, with the major rains falling between March and July and the minor rains between September and November. Average ambient temperatures range from 21°C to 32°C. The soils at the site belong to the Asuansi series and are classified as Ferric Acrisol (FAO/UNESCO). They are moderately deep and moderately well drained, gravelly and concretionary, and of low base saturation and low cation exchange capacity. The soil reaction is acidic (pH 5.3) in the top 10cm and extremely acid (pH 4.2) in the underlying horizon (Table 1).

Nursery Experiment

Seeds of Leucaena leucocephala and Senna siamea (scarified in hot water at about 98° C for 30 minutes) and Gliricidia sepium were sown into seedboxes containing a mixture of fine sand and topsoil in the ratio of 1 : 3. All boxes were watered after sowing and subsequently after every other day. Daily checks of germination were made on each day until 21 days after sowing (DAS) when seedlings were thinned to a spacing of 10cm x 10cm. From then onwards, weekly measurements were taken of growth in height and root collar diameter of 12 randomly selected seedlings, after which they were carefully pulled out of the soil and the roots gently washed to remove all soil particles. The length of the tap roots from the root collar to the tip of the longest root was measured. Each seedling was then separated into root and shoot portions, bagged and oven-dried to constant weight (65° C, 24 hours).

Field Experiment

A 95 x 13m plot was subdivided into three smaller plots of 30 x 12m. The tree species viz, L. leucocephala, G. sepium and S. siamea were randomly assigned to the plots in an unreplicated experiment and the seeds planted directly at a spacing of 2.0 x 0.6m. Each plot had seven rows of 50 trees/row or a total of 350 trees/plot. All plots were weeded regularly. Starting from 13 (WAS), and at fortnightly intervals, 10 trees were randomly selected from each plot (excluding the two outer rows) and their height, stem diameter at soil level and crown diameter were recorded. Two measurements of stem and crown diameters at right angles to each other were taken and an average value calculated. This continued till 51 WAS.

Sample plants (one per specie) selected from the middle row of trees on the basis of having height, stem and crown diameters close to average dimensions, were cut at soil level and returned to the laboratory for dry weight determination. Root sampling was done on volume basis. A 30cm x 30cm x 45cm volume block of soil around each sample plant was excavated and removed intact. The soil was carefully washed from the roots. Roots occurring in the 0 – 15cm and 15 – 45cm profile depths were separated for oven-dry biomass determination (65° C, 24 hours). Nodules where present were collected and nodule effectiveness determined by examining cut sections.

Fine Root Biomass Determination

Biomass of the roots (< 2mm in diameter) was determined at 52 WAS. Tube augur (6.5cm diameter) was used to sample soil at 12 positions (10cm, 20cm, 40cm, 60cm, 80cm and 100cm) from the base of the trees in two directions perpendicular to the rows of trees for each plot. Sampling was restricted to alleys undisturbed by previous destructive sampling, but excluding the two border alleys. Cores were taken to a depth of 30cm. Core samples were soaked for about 30 minutes in water and washed gently over a mesh sieve. The residue was hand-sorted to remove fragments consisting of roots, leaves and small stones. The fine roots were bagged for oven-dry biomass determination (65° C, 24 hours).

Total Root Exposure

At 53 WAS, one tree per specie sampled on the basis of having a tree height and stem diameter close to the average of 10 trees from each plot was carefully excavated. All roots were excavated by the skeleton method (dry excavation) digging along the course followed by the roots in the soil mass. Measurements were taken of maximum lateral spread and vertical root growth.

RESULTS

General Morphology and Rooting Pattern

Nursery Phase

In both nursery and field experiments, root growth and distribution pattern indicated that root systems of nursery seedlings and field grown plants were similar. It consisted of a strong downward growing root, the tap root, with lateral roots originating from the main root axis. In Leucaena and Senna, the roots initially developed faster than shoots (Figure 1–3) and mean root length to shoot height ratios of 1.41 and 1.46 respectively were recorded at the end of 9 weeks after sowing during the nursery phase. The reverse was the case for Gliricidia where a ratio of 0.72 was recorded. Due to good soil environment in the nursery boxes, there was a profuse proliferation of the roots on the laterals. It was more prolific on Gliricidia followed by Leucaena and then Senna. Dry weights and morphological characteristics are shown in Table 2. Dry weights of roots ranked in the order Gliricidia > Leucaena > Senna.

Field Phase

Like the nursery plants, field grown plants consisted of prominent tap roots that grew perpendicular and laterals that exhibited the tendency to spread nearly parallel to the ground surface (Figs. 4 to 6), but penetrating obliquely into the soil. In both Gliricidia and Senna the lateral roots had the tendency of occuring in "clumps" not being uniformly spaced along the parent axis. The laterals in Leucaena were more deeply placed than in Gliricidia and Senna. The number of first order laterals increased with age and constituted a major part of structural root length. The root biomass of all the three species increased considerably with age, and was directly related to the above-ground dry biomass and stem diameter at soil level of the respective plants, i.e. higher diameter produced higher root biomass. In 12 months old plants total root biomass was highest in Gliricidia and lowest in Leucaena. In the case of fine roots it was highest in Senna and lowest in Leucaena. Generally

Senna showed significantly higher growth than Leucaena but not Gliricidia (Table 3).

Root oven-dry biomass distribution calculated as a proportion of extracted root biomass apportioned to the 0 – 15cm soil depth during the periods 15–25 27–39 and 41–45 WAS is given in Table 4. The proportions were consistently lowest during the period 27–39 WAS (dry season) in the three species. Values for the two other periods 15-25 WAS (minor rainy season) and 41-51 WAS (major rainy season) were higher. Differences in mean values were significant between 27-39 and 41-45 WAS in all three species.

Nodulation

Qualitative observations were made on root nodule development. Nodules were observed on the roots of Leucaena and Gliricidia but not Senna. In Gliricidia nodules were concentrated on the main tap root a few centimeters below the root collar. In the case of Leucaena, there were fewer nodules on the main tap root. Nodules from Gliricidia were more pinkish than those from Leucaena. By the end of 31 WAS, no active nodules were observed on Leucaena roots. All nodules recovered after this period were small, hard and had a colourless inner pigmentation.

DISCUSSION

Root systems of trees play a very significant role in their growth. The growth and distribution of root systems of tree species usually depend on the genetic characters of the species, type of soil, biotic factors and method of planting (Chartuverdi et. al. 1986; Huck 1983). In the present study all the excavated trees had developed strong tap roots that exhibited the capability of penetrating the soil to great depths. A greater proportion of the roots (both fine and coarse) was found in the 0-15cm soil depth. The depthwise distribution of the root biomass indicated that the top 15cm of soil contained an average of 81.0, 82.3 and 80.3% of the total root biomass in Leucaena, Gliricidia and Senna respectively. All laterals were large structural elements, the primary function of which appears to be for anchorage. Although this property of accumulating a greater proportion of roots especially fine roots in the upper soil profile may offer poor physical support to the shoot system, (Dhyani et. al. 1990) have observed that it nevertheless provides enough absorptive surface to allow plants to have an easy access to water and nutrients in the top soil

The depthwise distribution of roots, especially during the various rainfall periods suggests that root systems have a capacity for compensatory growth in wet soil layers as an alternative to maintaining growth even in moderately dry soils. It is apparent from Table 4 that changes in the average proportions of root distributed to the 0 –15cm depth were strongly influenced by the availability of soil moisture during the periods 15-25, 27-39 and 41-51 WAS which correspond to the minor, dry and major rainy seasons respectively. The proportions were significantly higher during periods of rainfall than during the dry period. Between the two rainfall periods it was higher during the major rains.

Mayaki et. al. (1976) have stated that rooting densities in general are smaller near the surface but larger at greater depths in non-irrigated as compared to irrigated soils. Klepper et. al. (1973) working with cotton found that the percentage of roots distributed to the surface is higher when surface moisture conditions are good. The reverse was the case during dry spells. The results of the present study corrobarate those earlier findings.

Observations of core samples taken to a depth of 30cm at 52 WAS showed a pronounced decline in fine root biomass with depth. A similar pattern has been reported by Toky and Bisht (1992) in some tropical trees. They observed that out of nine tree species studied, root density was highest in the top 30cm soil layer and it declined sharply with increasing depth in all the species except in Prosopis cineraria and Acacia catechu which showed uniform distribution throughout the soil column. Jonsson et. al (1988) observed a more or less uniform decline in fine root biomass with increasing soil depth in two-year old stands of Senna siamea. Leucaena leucocephala. Eucalyptus tereticornis and

Prosopis chilensis. A similar pattern was observed by Dhyani et. al. (1990) in 28 month old stands of Leucaena leucoecophala, Eucalyptus tereticornis, Grewia optiva and Ougenia oogenensis but Bauhinia purpurea had its roots more or less evenly distributed down to 12m.

In the present study fine root densities of the three species determined after 52 weeks growth ranked in the order Senna > Gliricidia > Leucaena. This indicates that Senna would take up more water and nutrients from the soil than Gliricidia and Leucaena when grown under similar conditions. It would be expected that under conditions where below-ground resources are not limited, the more extensive the root system, the higher would be the expected nutrient uptake and contribution. This is because the species concerned would exploit a bigger soil area. Hauser (1993) has made a similar observation with Senna.

Maximum horizontal root spreads of 104.7, 98.2 and 93.0 cm recorded for Senna, Leucaena and Gliricidia respectively was less than crown spread in all the species studied. Root spread to crown spread ratio was 0.33, 0.59 and 0.73 for Senna, Gliricidia and Leucaena. This may increase with age since only 12 month old trees were studied in the present case. According to Prasad and Mishra (1984), root spread was 1.1 and 2.0 fold higher than crown spread in mature trees of Tectona grandis and Terminalia tomentosa.

As expected, Leucaena and Gliricidia nodulated. In the case of Gliricidia, root nodules were observed to be active throughout the duration of the study, though there was a reduction in number during the period 31-41 WAS (dry season). Dry conditions are known to reduce the number of nodules substantially (Beadle, 1964 and Corby et. al. 1983), and also do not permit the recovery of all the nodules. Generally nodule shape and morphology conformed to descriptions given by Corby (1971), varying from cylindrical to globular in Leucaena to irregular in Gliricidia. Nodules from Gliricidia were more pinkish in the interior than those from Leucaena. This indicates that the Rhizobium species responsible for the nodulation of Gliricidia formed a more effective symbiotic association with it than the association between Leucaena and the Rhizobium responsible for its nodulation. This is evident from the nodule pigmentation and the high dry matter yield in Gliricidia. Gliricidia is known to nodulate freely with diverse strains of Rhizobium, whereas Leucaena being exotic nodulates best with fast growing Rhizobia which are often lacking in our soils (Cobbinah, Personal Communication).

This observation emphasises the importance of assessing dry matter yield of leguminous MPTS in such a way that symbiotic performance is measured in relation to the growth potential of the host genotype supplied with adequate nitrogen. Reduced effectiveness of symbiosis may then be identified as a particular weakness of an otherwise productive MPTS and an attempt made to correct the situation. Required strains of Rhizobia can for instance be provided through innoculation. Innoculation of exotic species such as Leucaena has been found to increase total nitrogen and dry matter yield compared with uninnoculated plants (Sanginga et. al. 1985).

Results of this study and those of other workers indicate that root competition between annual crops and the tree species should be expected when they are interplanted unless some mechanisms of root exclusion such as trenching as described by Dadhwal et. al. 1984 and Prajapati et. al. 1971; root pruning (Roger and Rao 1990), or installation of root barriers (Singh et. al. 1989) is practised.

CONCLUSION

The present study shows that even though the tap and some lateral roots of the three tree species reach deep soil levels, the bulk of the roots (81% on the average) are found in the upper 0-15cm profile depth. It is likely that when grown in association with agriculture crops, they will offer serious competition for water and nutrients. The present observation and those of Jonsson et. al. (1988), Dhyani et. al. (1990) and Puri and Bangarwal (1992) on the distribution of Leucaena roots and that of other species do not support the contention that multipurpose trees in general have few roots in the topsoil and therefore would not compete with agricultural crops.

It is imperative that more attention is given to below-ground phenological studies of roots of MPTS when screening them for agroforestry technologies. Especially worth looking at is the possibility of manipulating hedgerow species through pruning management so as to form a root distribution pattern desirable for alley cropping. For instance van Noordjwik et. al. (1990) have found that in Peltophorum pterocarpa, lower pruning heights (25cm) produce finer branch roots in the top soil, while pruning at 75cm height resulted in the production of thick branch roots and smaller number of fine ones. Would other MPTS respond similarly?

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Table 1: Chemical Characteristics of the Soils of the Study Area

Depth (cm)	pH 1:1 H_2O	C ←	N %	O. M. →	Ca	Mg	K	Na Me/100g	Al	H →	ECEC (me/100g)	Base Sat. (%)
0 - 10	5.3	0.96	0.294	1.66	2.70	0.50	0.11	0.03	0.40	1.20	4.94	67.6
10 – 25	4.4	0.34	0.184	0.54	0.80	0.40	0.05	0.02	0.40	2.40	4.07	31.2
25 - 35	4.3	0.36	0.126	0.62	0.80	0.20	0.05	0.02	0.80	2.80	4.67	22.9
35 - 45	4.2	0.30	0.126	0.52	0.70	0.20	0.06	0.02	2.40	2.80	6.81	15.9

Table 2: Preliminary Observations on Rooting and Growth Characteristics of the Tree Species at 9 WAS

Observation	LL	GS	SS
1) Mean shoot height (cm)	31.1a	39.4b	22.0c
	(2.02)	(2.02)	(1.09)
2) Mean Tap root length (cm)	31.7a	28.3ab	27.1b
	(1.27)	(1.44)	(0.71)
3) Mean Root collar diam. (cm)	0.39a	0.63a	0.27c
	(0.01)	(0.32)	(0.01)
4) Shoot dry weight (mg/plant)	92.5	265.5	46.0
5) Root dry weight (mg/plant)	41.1	66.7	17.4
6) Total dry weight (mg/plant)	133.6	332.2	63.4
7) Shoot/Root Ratio	2.25	3.92	2.65

Values in the same row followed by a common letter are not significantly different ($P < 0.05$) as determined by the T-Test

Numbers in parenthesis are standard errors of means

LL - Leucaena leucocephala
GS - Gliricidia sepium
SS - Senna siamea

Table 3: Stand Characteristics. Total Fine Root (> 2mm diameter) Biomass. Root Spread and Depth of the Tree Species Studied. All Stands are 12 Months Old

Observation	LL	GS	SS
1. Mean shoot height (cm)	347.7a	367.5ab	386.6b
	(5.42)	(5.01)	(6.24)
2. Mean stem diameter at soil level (cm)	3.7a	4.98ab	5.80b
	(0.21)	(0.32)	(0.26)
3. Mean crown diameter (cm)	135.0a	159.0a	315.5b
	(8.64)	(12.8)	(16.4)
4. Root spread/crown spread ratio	0.727	0.585	0.331
5. Maximum lateral root diameter (cm)	2.92	3.90	4.0
6. Maximum lateral root spread (cm)	98.2	93.0	104.7
7. Maximum root depth (cm)	46.7	53.5	50.0
8. Fine root biomass			
kg/ha	91.7	125.0	158.3
kg/plant	0.011	0.015	0.019
9. Total root biomass kg/ha	289.6	809.1	472.4
10. Stand density/ha	8333	8333	8333

Values in the same row followed by a common letter are not significantly different ($P < 0.05$) as determined by the T-Test

Numbers in parenthesis are standard errors of means

Table 4: *Comparison of mean proportions of total extracted root biomass of Leucaena, Gliricidia and Senna distributed to the 0 – 15 cm soil depth during the minor, dry and major rainy seasons*

	PERIOD IN GROWTH CYCLE		
Species	**15-25 (WAS) (Min. Rainy season)**	**27-39 (WAS) (Dry season)**	**41-51 (WAS) (Maj. Rainy season)**
Leucaena leucocephala	0.81ab (0.031)	0.77b (0.042)	0.84a (0.018)
Gliricidia sepium	0.81a (0.012)	0.71b (0.028)	0.89a (0.019)
Senna siamea	0.82a (0.032)	0.70b (0.026)	0.89a (0.027)

Means of species followed by the same letter are not significantly different ($P < 0.05$) as determined by the T–Test

Number in parenthesis are standard errors of means

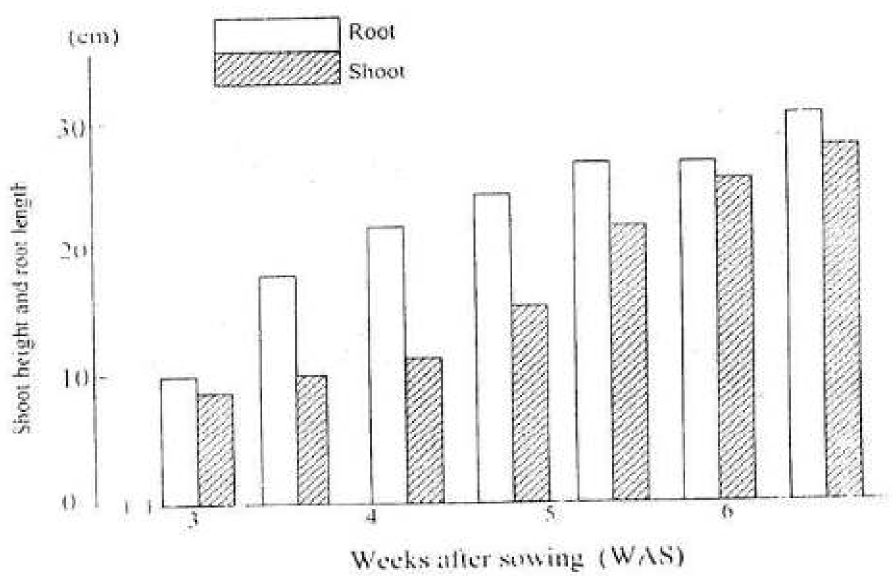


Figure 1: **Relative values of root length and shoot height of Leucaena leucocephala seedlings.**

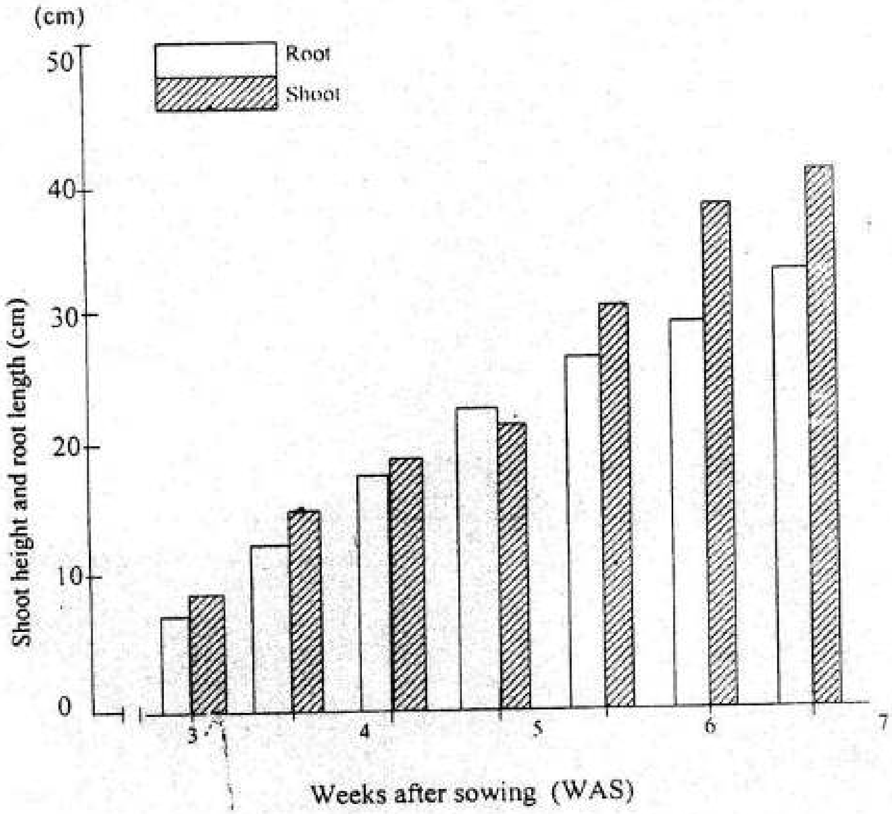


Figure 2: **Relative values of root and shoot height of Gliricidia sepium**

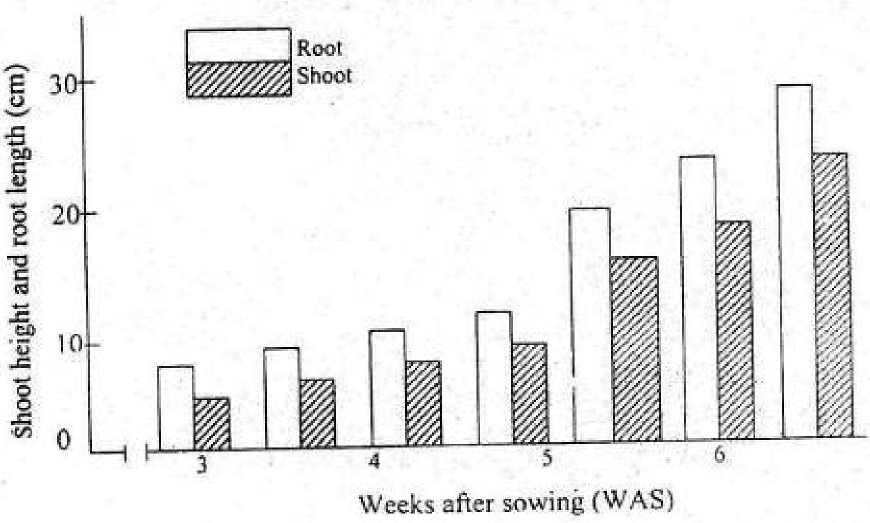
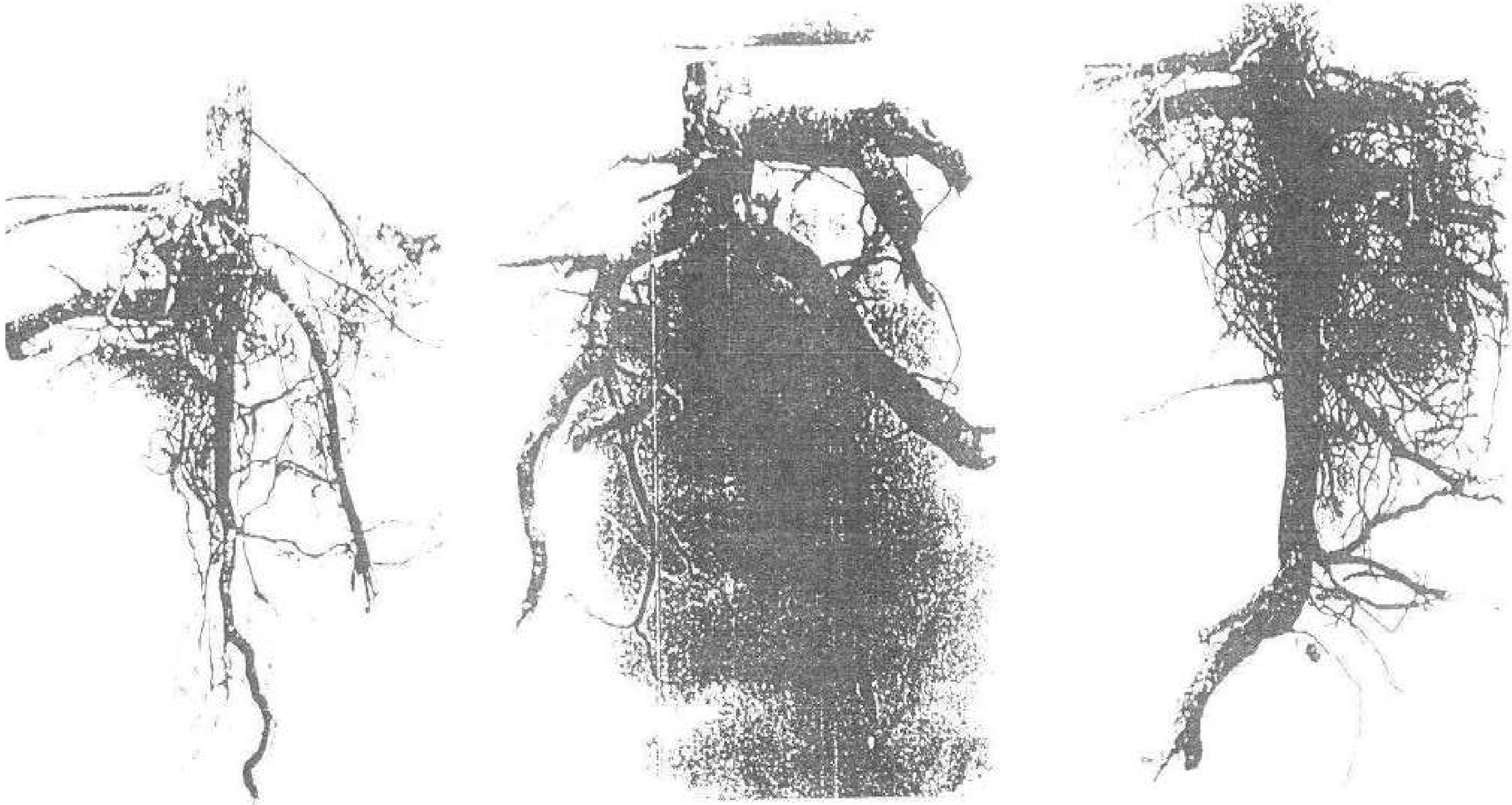
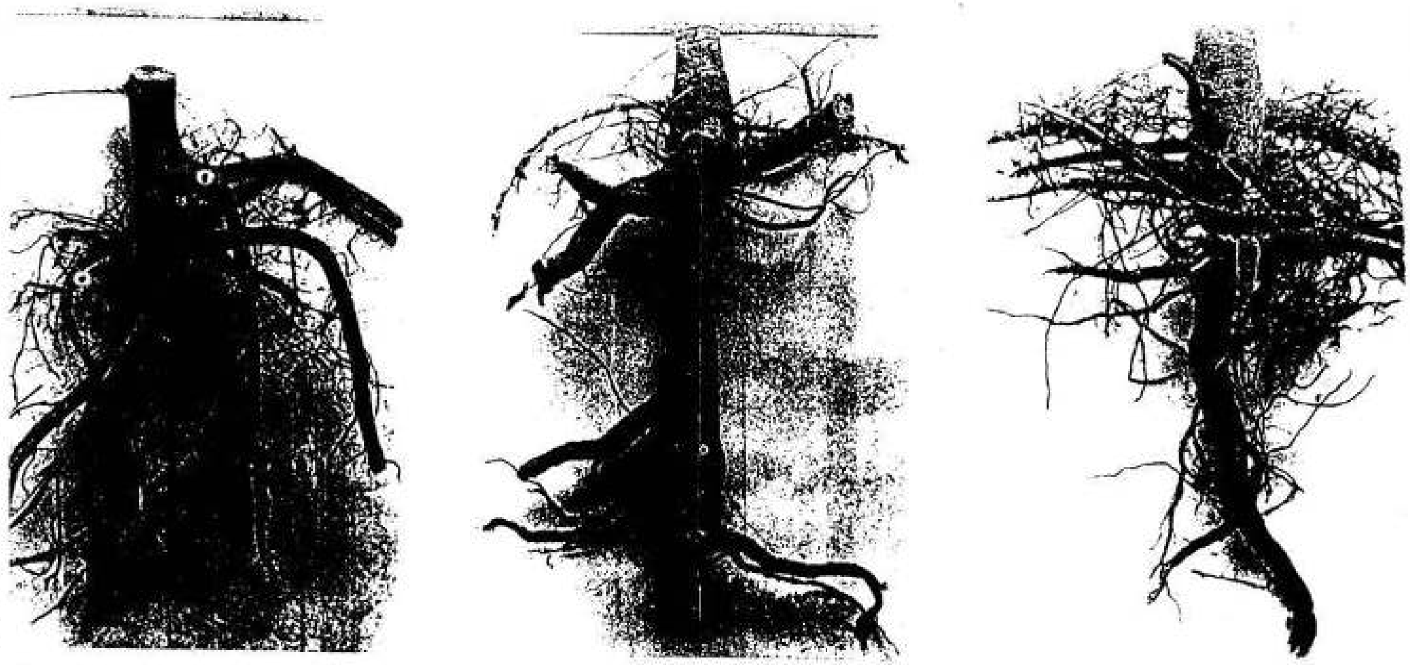


Figure 3 **Relative values of root length and shoot height of Senna siamea**

Figure 4. Root systems of Leucaena, Gliricidia and Senna at 25 weeks after sowing.



Senna



Leucaena Gliricidia Senna

Figure 6. Root systems of <u>Leucaena</u>, <u>Gliricidia</u> and <u>Senna</u> at 37 weeks after sowing.