THE ROOTING BEHAVIOUR OF FOUR AGROFORESTRY SPECIES IN THE WESTERN HIMALAYAN VALLEY REGION

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SINGH, R. K., NARAIN, P., DHYANI, S. K. & SAMRA, J. S. 2000. The rooting behaviour of four agroforestry species in the Western Himalayan valley region. The rooting behaviour of four agroforestry species in the northwestern hills of India, viz. *Bauhinia purpurea, Grewia optiva, Eucalyptus tereticornis* and *Leucaena leucocephala*, was investigated. Polybag-raised seedlings planted at 3 × 3 m on silty clay loam soil at Dehra Dun were excavated by the skeleton method periodically up to 90 months during the winter season. Along with the shoot growth patterns, rooting characteristics of these species were recorded in terms of changes in root length density, root weight, root system sorption zone and vertical and lateral expansions of roots with time. Above-ground biomass was closely related to root length and root biomass. The fast-growing species *E. tereticornis* and *L. leucocephala* had relatively more aggressive root systems than the slow-growing native spp. *G. optiva* and *B. purpurea*. At 90 months of age, more than one third of the root length of all the four species was positioned beyond 1 m depth. *Bauhinia purpurea* and *G. optiva* show much less root length density at 1 m depth compared to *L. leucocephala* and *E. tereticornis*. Therefore the former two indigenous species are likely to be less competitive with crops in agroforestry systems than the latter two fast-growing species. *Bauhinia purpurea* with a deep root system and high root:shoot ratio may be a suitable species for slope stabilisation while *G. optiva* with a shallow root system may be effective for erosion control particularly on terrace risers.

Key words: Agroforestry species - root system - rooting densities - root distribution - root:shoot ratio

SINGH, R. K., NARAIN, P., DHYANI, S. K. & SAMRA, J. S. 2000. Kelakuan pengakaran empat spesies perhutanan tani di kawasan lembah di Himalaya Barat. Kelakuan pengakaran empat spesies perhutanan tani di bukit di barat laut India, iaitu *Bauhinia purpurea, Grewia optiva, Eucalyptus tereticornis* dan *Leucaena leucocephala*, telah dikaji. Anak benih yang dibesarkan di dalam polibeg dan ditanam di tanah lom lempung berlodak berukuran 3 × 3 m di Dehra Dun telah digali menggunakan kaedah rangka dari semasa ke semasa sehingga 90 bulan pada musim sejuk. Bersama-sama pola pertumbuhan pucuk, ciri-ciri pengakaran spesies ini dicatatkan dari segi perubahan dalam ketumpatan panjang akar, berat akar, zon erapan sistem akar dan pemanjangan akar secara tegak dan secara sisian dengan masa. Biojisim atas tanah berkait rapat dengan panjang akar dan biojisim akar. Spesies cepat tumbuh *E. tereticornis* dan *L. leucocephala* mempunyai sistem akar yang lebih agresif secara relatif berbanding dengan spesies asli lambat tumbuh *G. optiva* dan *B. purpurea*. Pada usia 90 bulan, lebih satu pertiga daripada panjang akar bagi kesemua empat spesies ditempatkan di bawah kedalaman 1 m. *Bauhinia purpurea* dan *G. optiva* menunjukkan

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ketumpatan panjang akar yang sangat kurang pada kedalaman 1 m berbanding dengan *L. leucocephala* dan *E. tereticornis*. Oleh itu, kedua-dua lagi spesies asli *B. purpurea* dan *G. optiva* mungkin kurang bersaing dengan tanaman dalam sistem perhutanan tani berbanding dengan kedua-dua spesies cepat tumbuh. *Bauhinia purpurea* dengan sistem akar yang dalam dan nisbah akar: pucuk yang tinggi mungkin spesies yang sesuai untuk penstabilan cerun manakala *G. optiva* dengan sistem akar yang cetek mungkin berkesan untuk mengawal hakisan terutamanya di atas tanah yang bertingkat-tingkat.

Introduction

In recent years greater focus has been placed on agroforestry to increase production on a sustained basis. Soil–plant relationships in agroforestry systems are more complex than in monocropping systems as the former involve mixtures of more than two species, at least one of which is a woody perennial, arranged in time or space. A better understanding of the root growth pattern of potential multi-purpose species is required for quantitative explanation of some of the important processes like competition for water and nutrients, nutrient recycling from deeper layers, erosion control through root binding in surface layers and stabilisation of fragile steep slopes. Knowledge of horizontal and vertical distribution of fine roots helps in understanding competitiveness and exploitative efficacy of plants and their soil conservation potential. Roots, the hidden half of the plant, are not so well investigated as shoots owing to the problems associated with root sampling and cumbersome processing techniques. Most of the root studies have dealt with seasonal crops (Bohm *et al.* 1977, Prethapar *et al.* 1989, Ronn *et al.* 1996, Schortemeyer & Feil 1996) and a few with forest species (Eis 1974, Berish 1982, Prasad & Mishra 1984, Dhyani *et al.* 1996, Misra & Gibbon 1996); very limited cases have been published on agroforestry species (Jonsson *et al.* 1988, Dhyani *et al.* 1990, Toky & Bisht 1992, Schroth *et al.* 1996, Dunn *et al.* 1997).

In view of the growing need for a better understanding of the rooting pattern of multi-purpose trees (MPTs), a study was undertaken with four most preferred tree species of the Western Himalayan valley region to investigate their rooting behaviour in relation to shoot development.

Material and methods

Study area

This study was conducted at the Soil Conservation Research Farm, Selakui, located 18 km west of Dehra Dun at an altitude of 517 m (30° 20' N, 78° 2'E). Out of 1700 mm annual rainfall, about 80% is received from July to September. The temperature ranges from 3.5 °C (mean minimum in January) to 37.9 °C (mean maximum in June). The soil of the research station is fine loamy mixed hyperthermic Udic Haplustalf (U.S. Soil Classification, Soil Survey Staff 1975) with silty loam texture in the surface and silty clay in the subsurface layers. The physico-chemical properties are given in Table 1.

Table 1. Physico-chemical characteristics of the experimental site

Soil depth (cm)	Texture	Bulk density (g cm^{-3})	pH (%)	Organic C (%)	Total N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})
0–15	Sil	1.31	5.5	0.58	0.094	16.53	230.40
15–30	Sicl	1.42	5.5	0.47	0.081	12.13	197.60
30–60	Sicl	1.46	5.6	0.30	0.063	9.87	168.00
60–100	Sicl	1.51	5.5	0.17	0.068	10.19	168.00

Sil = silty loam, Sicl = silty clay loam.

Experimental set-up

An experiment was conducted from July 1985 to December 1994 with four tree species, viz. *Bauhinea purpurea, Grewia optiva, Eucalyptus tereticornis* and *Leucaena leucocephala.* Polybag-raised four-month-old seedlings of all four species were planted in a randomised block design with four replications at 3 × 3 m spacing. Each treatment had 25 plants, i.e. a total of 100 plants for each species with an intensity of 1111 plants per hectare. All the plots were maintained with regular hoeing and weeding.

Plant growth measurements

Periodic measurements for plant height and diameter at breast-height (dbh) were recorded. Two trees of each species with average dbh and height were cut and fresh and air dry phytomass recorded at 16, 28, 42, 64 and 90 months after planting.

Root excavation

The entire root systems of two representative trees from each species were excavated using the skeleton method (Bohm 1979) after 6, 16, 28, 42, 64 and 90 months of planting and the results of two samples were averaged for each date. Trees were subjected to root excavation during the winter when the soil remains friable. Root excavation was initiated by opening 1-m wide trench around a 3 × 3 m monolith retaining one tree in the centre. While tracing branch roots, excavation was gently progressed inwards using small hand tools like pick-axe, spade and metal forks. To minimise the loss of fine roots during excavation, extra care was taken in removing soil particles around the roots. Roots were anchored with string to retain their normal positions throughout the excavation (Figure 6).

Root length measurements

Root systems, retained in natural positions, were gently washed to remove soil particles. The root systems were then placed over a 50-cm grid and roots falling in each grid were clipped radially inward and labelled separately for each grid.

Total root lengths per unit volume of soil under various diameter classes (< 2, 2–5, 5-10 and > 10 mm) were recorded separately for each grid. Root lengths of more than 2 mm diameter were measured directly. Fine roots (< 2 mm diameter) were measured either directly or by the intersection (Tennant 1975). The root length density (L_v) values are the averages of four 50-cm grids located in similar vertical and horizontal planes.

Root system sorption zone

The root system sorption zone refers to the total volume of soil occupied by the entire root system. This has been estimated for each 50-cm segment down to the depth of root system on the basis of mean radial spread of root system in the respective segments.

Fine root sampling

For estimating loss of fine roots during the excavation, roots were sampled with a hand core sampler having 7.5-cm diameter and 175-cm length. Sampling was done at randomly selected points in 0–50 cm horizontal segments from trees and successively for every 25 cm down to 150-cm depth. Eight samples were taken for each species from each depth. The presoaked core samples were gently washed over a 32-mesh sieve and root length, fresh and oven dry weights were measured. The intersection method was used to measure the root length of each sample.

Profile water sampling

Soil water depletion pattern is indicative of relative root activity at different soil depths and competitive aggressiveness of the tree species in agroforestry combinations. Depletion in the profile water content under the four species was monitored gravimetrically down to 120-cm depth. Soil water sampling was done under four- and seven-year-old plantations at the end of the monsoon in October and before the onset of the monsoon in June when profile water content was expected to be minimum.

Results and discussion

The shoot growth pattern

The exotic species *E. tereticornis* and *L. leucocephala* showed much faster growth as revealed by height, dbh and phytomass accumulation compared to the native species *G. optiva* and *B. purpurea* (Figure 1). At 64 months and 90 months after planting, *L. leucocephala* and *E. tereticornis* accumulated about twice and four times higher phytomass respectively compared to *G. optiva* or *B. purpurea*. *Eucalyptus tereticornis* expressed the highest growth rate throughout the experimental period, especially from the age of 28 months whereas shoot biomass accumulation in *L. leucocephala* exceeded that of *G. optiva* or *B. purpurea* only after 4-y planting. The branching pattern differed considerably between the species and therefore plant height or dbh does not seem to be a suitable indicator for between-species comparison of shoot growth patterns.

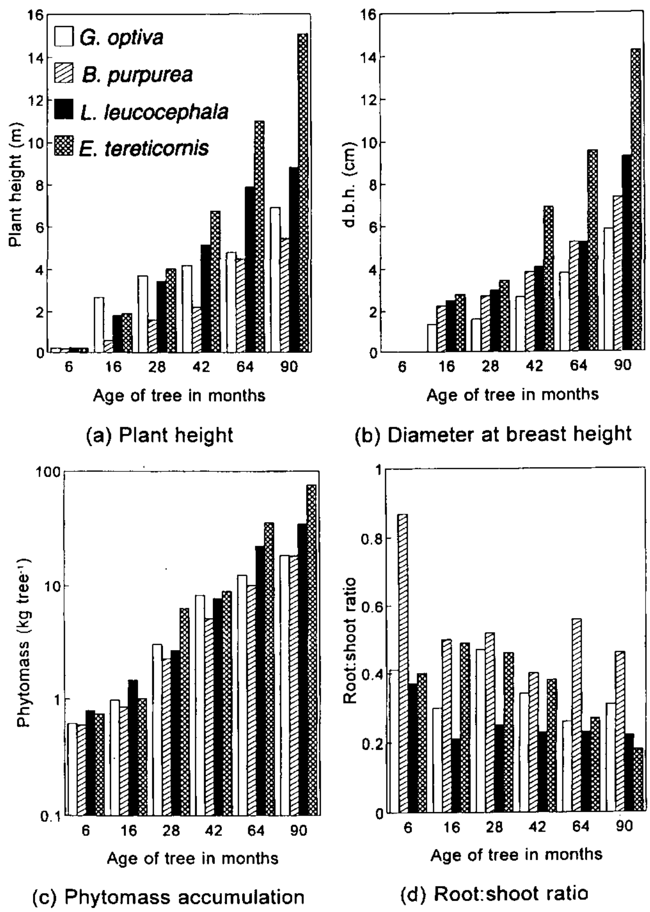

Figure 1. Above-ground growth pattern of trees

Root growth patterns

Rooting patterns of all the four species were found noticeably different from each other (see comparison in Figure 7). *Eucalyptus tereticornis* shows an intensive rooting system concentrated around a well-developed tap root and branching takes place throughout the rooting depth, whereas the other three species have a spreading type of root system with well-developed lateral roots branching out from within 25-cm depth and tap roots were not prominent. Lateral roots extended equidistantly around the root system in all species except *B. purpurea* in which radial expansion of roots was not symmetrical.

Root system development with age of trees

Grewia optiva showed the maximum lateral expansion of the roots (Figure 2a). Although *E. tereticornis* had the minimum lateral spread of root system, it continued to expand even after 64 months of age when other species had restricted lateral growth of roots.

The root system sorption zones of all species (Figure 2d) expanded geometrically with time. The specific growth rates of the species resulted in widening difference between the species in the volumes of the root system sorption zones with time. *Grewia optiva* and *L. leucocephala* root systems exploited greater volumes of soil than other two species until 42 months age. After the fifth year, *L. leucocephala* and *B. purpurea* root systems expanded more rapidly than the other two species. Since *E. tereticornis* root system intensified around the tap root, it had minimum volume of sorption zone in spite of maximum root biomass and total root length (Figures 2 b & e).

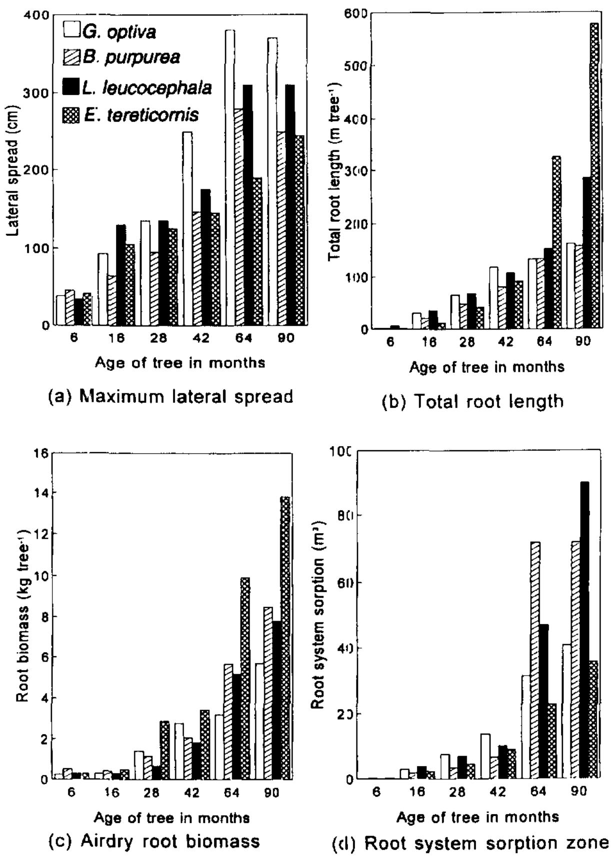

Figure 2. Root growth pattern of trees

Eucalyptus tereticornis and *B. purpurea* had relatively deeper root systems than the other two species. After an initial rapid vertical expansion during the first five years, these species showed delayed horizontal growth of roots (Figure 3).

However, *G. optiva* and *L. leucocephala,* with relatively shallow root systems and early horizontal expansion, continued to grow vertically even after 64 months of age.

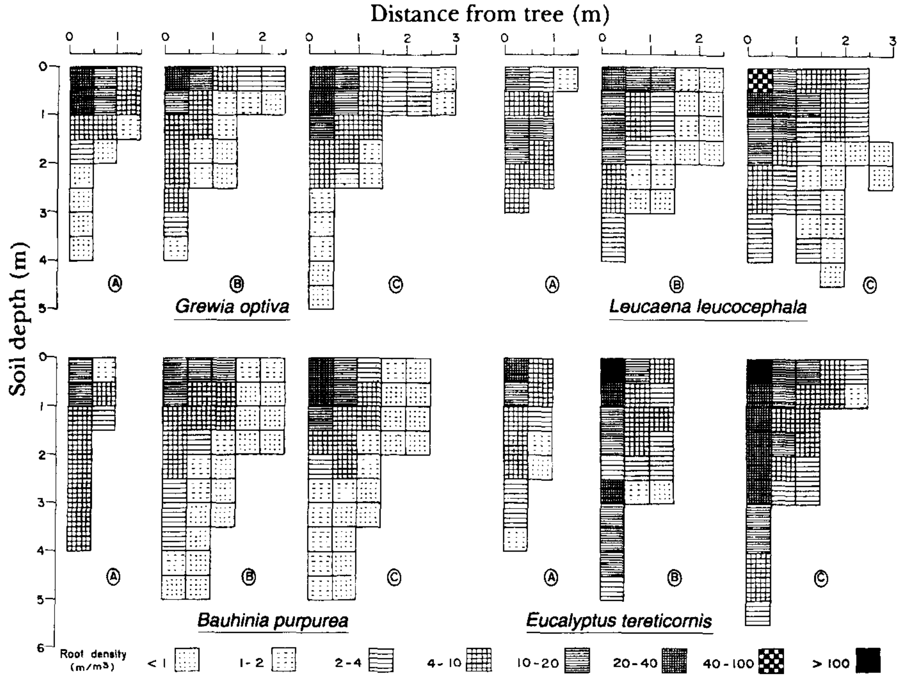

Figure 3. Root length density (m m^{-3}) at (A) 48 months, (B) 64 months, and (C) 90 months of age

Density distribution of roots

Changes in total root length density with time and space are presented in Figure 3. At 64 and 90 months the proportion of fine roots (< 2 mm) in *G. optiva* and *B. purpurea* ranged 79–91% of the total length recorded, where as it was 96–98% in *E. tereticornis* and *L. leucocephala.* The observed rooting length density values ranging from 0.2 to 262 m m^{-3} are very low compared to the reported values for agricultural crops (470 to 7800 m m^{-3} in wheat, Haberle *et al.* 1996; up to 2400 m m^{-3} in sorghum, Savage *et al.* 1996; 1000 to 8000 m m^{-3} in cotton, Plauit *et al.* 1996). However, Jonsson *et al.* (1988) compared 2-y-old stands of *Cassia siamea, E. camaldulensis, E. tereticornis, L. leucocephala* and *Prosopis chilensis* with maize and reported that the average fine root biomass of trees was roughly twice that of maize.

Although the dry excavation method tends to underestimate root length density compared to the core method, large differences between observed tree root densities compared to reported values for crops indicate that theoretically trees could be weak competitors for nutrient and water at tree–crop interfaces when a well-developed crop root system is compared with tree roots. Nevertheless, crop yield depressions near the trees have been frequently reported (Khybri *et al.* 1983, Singh *et al.* 1989, Rosecrance *et al.* 1992, Mureithi *et al.* 1994) indicating preferential access of trees to above- and below-ground resources. Reduction in crop yields involves complex tree–crop interaction. Among several possibilities, moisture depletion by the tree roots before crop root system are developed and/ or light stress at the interface where tree canopy has an advantageous position could be reasons for crop yield reduction. More data on tree–crop competition and their rooting patterns are required for any definite conclusion.

Among the four species, though the shallow root system of *G. optiva* had maximum horizontal expansion in the upper 1-m depth (Figure 3), *E. tereticornis* and *L. leucocephala* are expected to be more competitive than *G. optiva* up to the distance of 2 m as indicated by greater root length densities in the surface layers. *Bauhinia purpurea* had early vertical expansion and showed minimum rooting density in the surface layers. Traces of mycorrhizae were also observed in the surface layers (0–25 cm depth) which might have some effect in increasing root activity in shallow depths.

Dry excavation results in considerable loss of fine roots compared to core sampling. Losses of fine roots of about 30–42% were observed by dry excavation of *E. tereticornis* and *L. leucocephala* as compared to that of *G. optiva* and *B. purpurea.* The higher excavation losses of 47–61% in the latter species may be due to possible differences in tensile strength and fragility of roots. This indicates that large differences in root length densities among the species could have arisen partly from sampling error.

Vertical distribution of roots

Roots of the 90-month-old trees were observed to penetrate up to 4.35–7.15-m depth; however, about 90% of the total root lengths of trees were confined within 2 m and 3 m for *G. optiva* and *E. tereticornis* respectively and 2.5 m in the case of *B. purpurea* and *L. leucocephala* (Figure 3). Since root length is one of the best parameters relating to the uptake of water (Taylor & Klepper 1974, 1975) and nutrients (Nye & Tinker 1969), depthwise distributions of root length can be used to assess the relative exploitation profile for water and nutrients. While root systems of most agricultural crops are confined to within 1-m depth, more than one-third of the total tree root length at 90 months of age was found to extend beyond 1-m depth and can potentially utilise subsoil fertility and moisture which is unexploitable by most agricultural crops. *Bauhinia purpurea* had maximum proportion, about half of total root length, extending beyond 1-m depth.

Relationship between root and shoot growth

Species with higher rate of biomass production are expected to have more prolific root systems to meet increased demands of nutrient and water. *Eucalyptus tereticornis* and *L. leucocephala* showed distinctly higher growth rates than the indigenous multipurpose species *G. optiva* and *B. purpurea* (Figure 1). Root length and root biomass also increased with above-ground biomass, but, in general, root:shoot ratio tends to decline with advancement of growth beyond 28 months (Figure 1d). In spite of the highest rate of increase in the root biomass of *E. tereticornis* (Figure 2c), root:shoot ratio sharply decreased with time, which was not so apparent in other species. *Bauhinia purpurea* maintained the highest root:shoot ratio. After 64 months of planting rapid increase in the total root lengths of *E. tereticornis* and *L. leucocephala* corresponded well with the increased above-ground biomass growth rate recorded for these species during the same period.

Distribution of root biomass under different diameter classes, as observed from the excavation of 90-month-old trees, show that fast-growing trees like *E. tereticornis* and *L. leucocephala* have greater proportions of total root weight as fine roots compared to slow-growing species like *G. optiva* and *B. purpurea* (Figure 4). All the four species markedly differ in proportional distribution of root biomass in different diameter classes, although these are static values which do not show seasonal fine root dynamics. *Bauhinia purpurea* had about 50% roots in the 2–5 mm class; *E. tereticornis* and *L. leucocephala* had 35% roots in the 5–10 mm class, while *G. optiva* had the largest proportion of its root weight in the >10 mm diameter class.

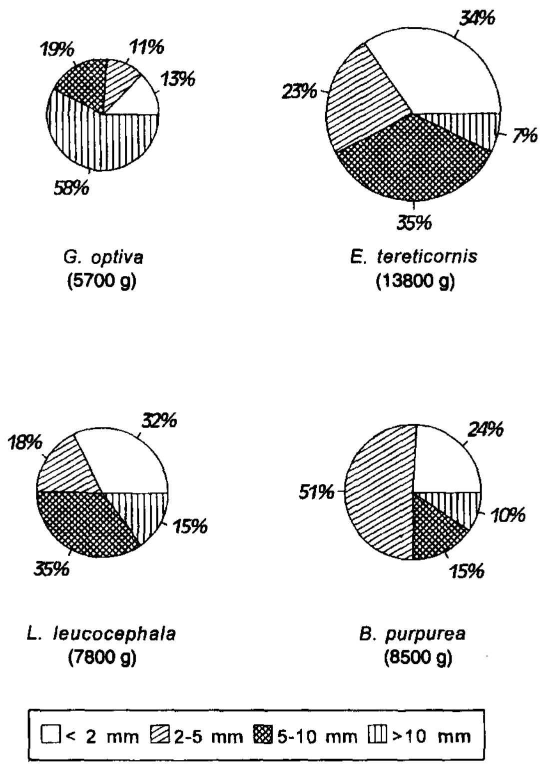

Figure 4. Root biomass under different diameter classes (*values in parentheses are total air dry weights of roots)

Erosion control efficacy of root systems

Soil binding factor (w/r^2, where w is the root weight density and r is the average radius of roots) has been used to assess soil binding efficacy of grasses through fine root network (Bhimaya *et al.* 1956, Khybri & Mishra 1967). Root length density, perhaps, can serve as a better index for this purpose. Because intensive tree root network is limited to 50-cm radial distances (Figure 3), trees alone may not be very effective in controlling surface erosion and undergrowth is expected to play an important role. Trees, however, can effect mass erosion control through their deeper and stronger root systems. Root diameter, tensile strength and distribution of structural roots are criteria for quantifying erosion control and slope stabilisation efficacy of trees. Although data on tensile strength and soil erosion under the trees were not collected in this study, some suggestions can be made based on root architecture of the trees. *Bauhinia purpurea* with its deep root system and high root:shoot ratio could be a suitable species for stabilising fragile slopes and needs further evaluation for this purposes. The shallow root system of *G. optiva* showed rapid horizontal spread and therefore, may be appropriate for strengthening terrace risers, since it is often seen in the hilly terrains of north-western India.

Soil water depletion

Post-monsoon profile water depletion pattern during the 8-month period from October to May show considerably higher water removal by 7-y-old trees compared to 4-y-old trees (Figure 5) particularly from the deeper layers beyond 90 cm, suggesting an increased root activity with time in the deeper layers. Greater water depletion down to 30-cm depth under younger plantations may be due to lack of shade and litter effects and yearly rainfall variations. The order of water depletion in terms of depth at 4 y age was 0–30 > 30–75>, 75–120 cm which shifted to 75–120 > 30–75> 0–30 cm at the age of 7 y. Depthwise water depletion did not follow root length density patterns which may be due to moisture redistribution through internal fluxes in the profile and intermittent winter rains.

Actual water depletion in plants of 4 and 7 y age revealed that *E. tereticornis* consumed maximum water in both age groups, which was followed by the 7-y-old *L. leucocephala*. Thus fast-growing trees deplete higher profile water than slow-growing ones. This was reported from water balancing studies at this experimental station (Narain *et al.* 1998). *Grewia optiva* and *B. purpurea* seem to be much less competitive and therefore be more suitable for integration in agroforestry systems with crops.

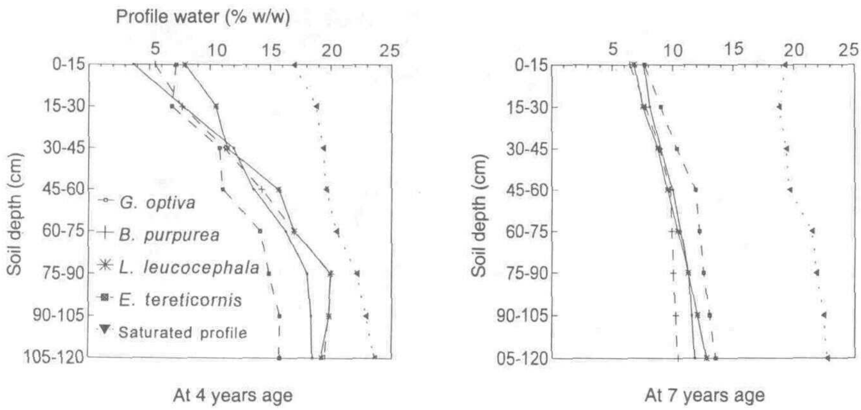

Figure 5. Post monsoon profile water depletion by trees from October to June

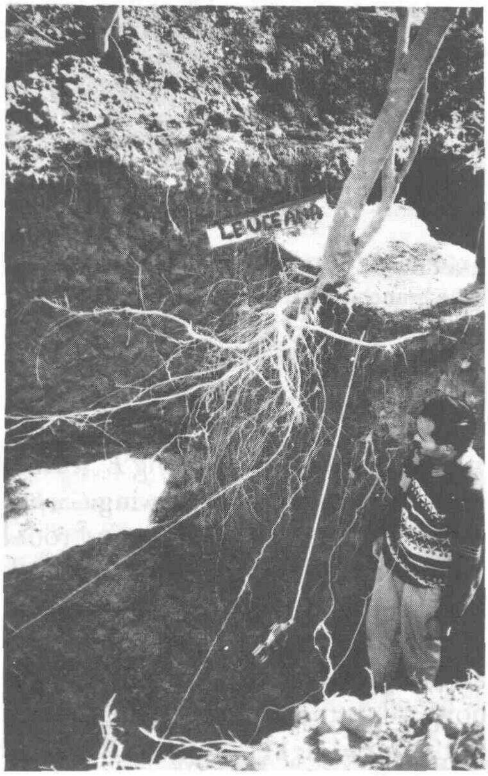

Figure 6. Root excavation of 90-month-old *Leucaena leucocephala* in progress

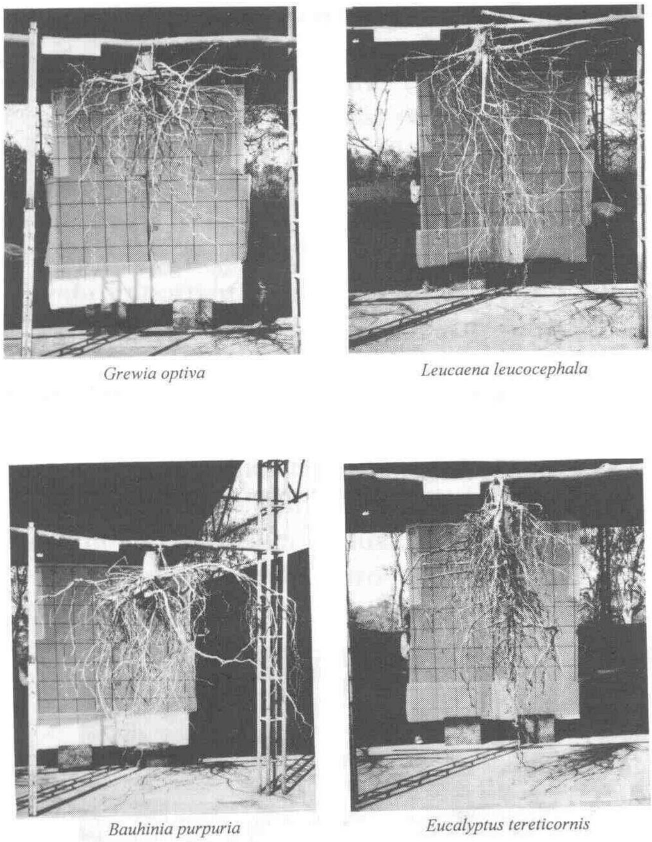

Figure 7. Root system of MPTs after 90 months of planting: note the branching pattern, lateral and vertical elongation

Conclusion

This study clearly demonstrates that fast-growing *E. tereticornis* and *L. leucocephala* have more aggressive root systems than slow-growing *G. optiva* and *B. purpurea.* The shoot growth rates are also related to root length and root biomass development. However, root:shoot ratio tends to decline with rapid shoot growth. In isolated systems, lower rooting density has been observed for all the four tree species compared to reported values for crops. This implies that even the fast-growing species may not be a strong competitor for moisture or nutrients with crops. Ensuring adequate moisture at the establishment of crops in conjunction with shoot management to minimise light competition should be focused upon to improve tree-crop compatibility in agroforestry systems. All the species have shown considerable potential in using subsoil fertility and moisture. Considering root length densities and water depletion patterns, native species like *B. purpurea* and *G. optiva* show better promise for integration in agroforestry systems compared to *L. leucocephala* or *E. tereticornis.* Further, *B. purpurea,* with a deep root system, high root:shoot ratio and shorter canopy, could be a suitable species for slope stabilisation, whereas *G. optiva,* with a shallow and spreading type root system and commonly occurring in hilly regions, may be an appropriate species for the prevention of erosion from terrace risers.

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