(0-100 cm above ground level) in the first three years. A pruning height of 50 cm was recommended to maximize firewood production. Coppicing at a 25 cm level [illegible] equal number of branches, but a lower volume. In our research another [illegible] effect of the pruning height was recorded: it appears to be possible [illegible] ice the root distribution pattern by pruning. More but finer branch [illegible] the topsoil are formed when the trees are pruned at a low level. The appa[illegible] ns of apical dominance in the root system under a pruning regime coincides with the loss of apical dominance in aboveground growth, leading to a shrub-like form. Increasing the pruning frequency may have an effect similar to that of reducing pruning height. To obtain a suitable rooting pattern in alley cropping it may be necessary to delay the first pruning at least till the stage in which the trees studied here were first pruned (stem height 2 m) to allow a good taproot development, and to subsequently prune at a height of 75 cm. Later, pruning frequency may be increased to avoid thick horizontal branch roots developing into the zone intended for crops in the alley cropping system. Further observations on rooting pattern under such a pruning regime are required.

Acknowledgements Dr. Riswan (Herbarium Bogoriense) helped in the identification of *Peltophorum*, Ir. K.F. Wiersum supplied us with bibliographic references on this tree.

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Plant roots and their environment
B.L. McMichael and H. Persson

CASTOR ROOTS IN A VERTIC INCEPTISOL

G.D. SMITH, L.S. JANGAWAD and K.L. SRIVASTAVA
Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India.

ABSTRACT

The root systems of four large and four small, mature castor (*Ricinus communis* L.) plants were excavated. Large and small plants had similar root/shoot ratios but roots of small plants were longer per unit weight. Soil factors in or near the surface of the C_1 horizon - probably higher gravel and carbonate content - apparently restricted root penetration.

INTRODUCTION

Vertic soils resemble,but are too shallow to be classified as, Vertisols. India has over 40 million ha, and there are large areas in Africa and Australia. They are often stony or gravelly, easily erodible, and have low plant available water capacity, either because of the coarse mechanical composition of the subsoil or the inability of roots to penetrate subsoil. Farmers in India often grow castor (*Ricinus communis* L.) on such difficult soils--a tacit recognition that it has an aggressive root system. However, very little is known about castor root systems, how they respond to difficult soil conditions, what soil factors affect root system development, and how root system development affects plant top growth. This paper reports a preliminary study on these topics.

2. MATERIALS AND METHODS

The experiments were conducted on a Vertic Inceptisol (Paralithic Vertic Ustropept, eroded phase) at ICRISAT Center, Patancheru (17°N), India. Castor (cv Aruna) was grown in 1986/87

Submitted as ICRISAT Conference Paper No. 501.

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season. When this crop was mature (March 1987), a range of plant sizes was evident. The soil around selected plants (4 relatively large and 4 relatively small plants) was ponded with water for 12 h and then drained. The soil was carefully excavated, and the root system traced until the diameter of roots was <2 mm. Root length and diameter at intervals and root and top dry weight were measured. The root system was sketched as the excavation proceeded. The soil exposed in the profile wall was examined, and visible physical features noted. Samples were taken for determination of particle size distribution, pH, electrical conductivity, and carbonate content, by standard methods used at ICRISAT. Bulk density and water content were measured by taking core samples from the pit wall; a hand-held vane shear instrument (Pilcon type) and a pocket penetrometer (tip diameter 6.1 mm) were used to indicate soil strength.

3. RESULTS

3.1. Plant components

Results are shown in Table 1. The root/shoot ratio for large plants is not significantly different from that for small plants. Root length per unit root mass ranged from 4.0 to 8.4 cm g^{-1} for large plants, and from 14.5 to 32.6 cm g^{-1} for small plants. Root length per unit of shoot mass ranged from 0.8 to 2.0 cm g^{-1} for large plants, and from 3.2 to 13.2 cm g^{-1} for small plants.

3.2 Root system structure

Plant size was not related to the depth of root penetration. The structure of root systems varied; in some plants, one or more lateral roots appeared to take over from the tap root. Examples of root distribution patterns are shown for 2 large and 2 small plants in Fig. 1. Considering all 8 plants as a group, irrespective of plant size, the number of major roots initiated at soil depths shallower than 30 cm was 62 (both lateral and tap

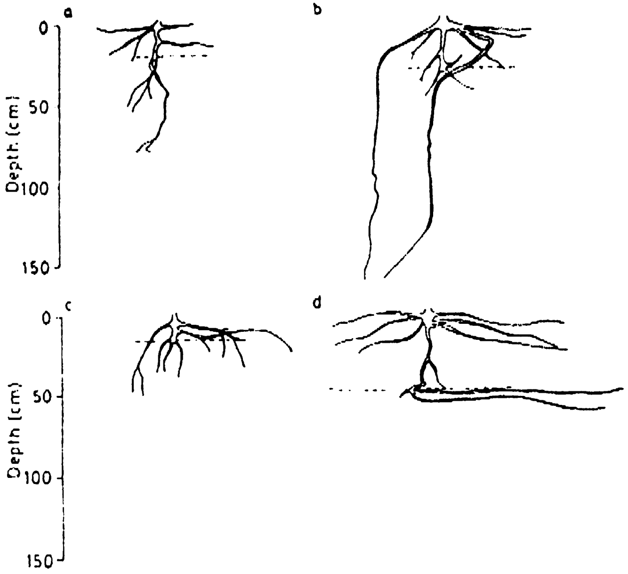

Figure 1. Diagrams of root patterns (diameters not to scale) for 2 small (a and c) and 2 large (b and d) mature castor plants. Dotted line marks the upper surface of the C_1 horizon.

roots). Of these, only 11 penetrated deeper than 50 cm but in this group of 11 roots, 8 grew beyond 100 cm.

TABLE 1

Above-ground and below-ground components for large and small mature castor plants on a Vertic Inceptisol, postrainy season 1986, ICRISAT Center, Patancheru, India.

Plant components (mean values)	Large plants	Small plants	Sign.[1] diffs.
Plant ht (m)	2.98	1.83	*
Shoot mass[2] (g)	921.0	115.3	**
Root length[3] (cm)	1191.7	546.7	***
Root mass (g)	201.2	26.7	**
Root mass/shoot mass ($g\ g^{-1}$)	0.22	0.25	NS
Root length/root mass ($cm\ g^{-1}$)	6.28	22.[illegible]	*
Root length/shoot mass ($cm\ g^{-1}$)	1.29	4.74	*

1. NS = not significant at $P < 0.05$, based on "t" test;
   * = significant $P < 0.05$;
   ** = significant $P < 0.01$;
   *** = significant $P < 0.001$.
2. Oven dry
3. Roots of diameter >2 mm.

3.3 Soil characteristics

Three soil layers were identified in each pit:

1. A surface Vertic layer, the lower boundary of which ranged from 15 to 45 cm (referred to as the A horizon);

2. a calcareous layer of strongly weathered parent material, often with gravel and stones, with a lower boundary ranging from 40-70 cm (referred to as the C_1 horizon); and

3. a less calcareous layer of weathered parent material (referred to as the C_2 horizon)

The properties of each layer are shown in Table 2. There are significant differences between the A and C_1 horizon for 10 of the measured properties, but between the C_1 and C_2 horizon only the cation-exchange capacity shows a significant difference ($P<0.05$). Gravimetric water content tends to be higher, and gravel and carbonate content to be lower ($P<0.1$), in the C_2 horizon than in the C_1 horizon.

4 DISCUSSION AND CONCLUSIONS

4.1 Plant components and plant size.

The similar root/shoot ratios (Table 1) found for large and small plants suggests that root system development influenced plant biomass. However, the higher ratio of root length/root mass (Table 1) for small plants than for large plants shows that small plants apportioned relatively more photosynthate towards increasing root length rather than root diameter. If roots function most effectively by exploring the soil, root system development does not appear to restrict plant size. One explanation may be that small plants put relatively more carbon into growing longer roots to increase chances of intercepting, and thus increasing the supply of a deficient factor that limits top growth. There was no significant difference (results not shown) between small and large plants in either the number of lateral roots or the depth to which roots penetrated vertically. Thus small plants spent a relatively greater proportion of energy in an apparently fruitless extension of the length of the root network. Because the large and small plants occurred more or less at random in the field, it is difficult to invoke a nutritional deficiency to explain the different root-growth patterns. Possibly the smaller plants emerged somewhat later and had a comparatively restricted supply of water or nutrients, which may have influenced root growth. Another explanation may be that when roots come under stress from soil strength or dryness, cytokinin production or translocation is modified and this limits shoot growth (Masle & Passioura, 1987; J.M. Peacock, ICRISAT, pers. comm., unpublished, 1988). This could explain why top growth is restricted in relation to root length extension. If this hypothesis is correct, further research is needed to determine how the plant integrates the various stresses on the root system, and to explain what degree of stress on what proportion of the root system restricts top growth. Some genetic variability in the cultivar Aruna is also possible, and this may be expressed in plant size and root system development.

TABLE 2

Properties of soil horizons found during excavation of castor root systems on a Vertic Inceptisol, postrainy season 1986, ICRISAT Center, Patancheru, India.

Properties	A horizon (mean)	P	C_1 horizon (mean)	C_2 horizon (mean)	P
Bulk density (g cm^{-3})	1.37	0.01	1.54	1.54	NS
Gravimetric water (%)[1]	23.2	0.01	16.6	18.7	0.10
Shear strength (KPa)	12.0	0.01	27.3	23.1	NS
Penetrom. resist. (MPa)	0.99	0.01	2.51	2.35	NS
Gravel >2 mm (%)	22.6	0.01	39.6	30.6	0.10
Coarse sand (%)[2]	26.8	0.01	38.3	32.2	NS
Fine sand (%)	20.8	NS	18.9	25.6	NS
Silt (%)	16.6	NS	15.5	17.1	NS
Clay (%)	35.8	0.01	27.3	25.0	NS
pH	7.98	0.01	8.35	8.38	NS
Electr. cond. (dS cm^{-1})[3]	0.146	0.01	0.118	0.113	NS
Carbonate[4] as CaC03 (%)	3.3	0.01	18.8	11.5	0.10
CEC[5] (meq %)	22.4	NS	21.0	25.9	0.05

1. % = mass % of whole soil for water and gravel; of soil <2 mm for other sizes.
2. Coarse sand, 2.0-0.2 mm; fine sand, 0.2-0.02 mm; silt, 0.02-0.002 mm; clay, 0.002 mm; method: ASTM (1971).
3. Electrical conductivity 1:5 water extract.
4. Method: Allison & Moodie (1965).
5. CEC = Cation-exchange capacity; method: Chapman (1965).

4.2 Soil factors and root depth

The linkages between root-system attributes and plant size and the possible mechanisms involved are obscure. However, if stress is imposed on the root system by soil factors, a guide to these factors and the plant's ability to explore the soil environment (and hopefully to avoid stress) can be obtained by considering the depth to which roots penetrate and the morphology of the root system in relation to soil features.

Because there is no significant difference between large and small plants in the depth of the A horizon or the number of roots penetrating the C_1 horizon, we combined plant sizes when examining soil factors that restrict root penetration. Two observations sum up root morphology and soil depth effects:

1. Many roots ended, branched, changed direction abruptly (including growing horizontally), were constricted, pitted, or deformed near or in the surface of the C_1 horizon or stones associated with it.

2. If roots penetrated into the C horizon to 50 cm, then most grew deeper than 100 cm.

These observations show that factors in or near the surface of the C_1 horizon affect root growth. Several soil properties show significant differences between the A and C_1 horizons (Table 2). It is of course impossible to deduce from analyses of soil samples that are large relative to, and separated in time and space, from the root tips, the precise factors that limit root penetration of the C horizon. However, many roots grow only partly into the C_1 horizon, but most of those that grow to 50 cm grow on beyond 100 cm in the C_2 horizon. Therefore, indications of the factors in the C_1 horizon that restrict root penetration can be sought by comparing properties of the C_1 and C_2 horizons (also because these horizons are more alike than the A and C_1 horizons).

In terms of physically constant properties, the C_2 horizon tends to have less carbonate, less gravel, and slightly more active clay (because clay content is similar but cation-exchange capacity is higher). This suggests that it may be lack of root-size pores and high mechanical impedance due to bridging between gravel particles that restricts root penetration into the C horizon. Vine et al. (1981) and Babalola & Lal (1977) found that gravel restricted root growth. Gravel layers have been observed to restrict root penetration in Alfisols in Sri Lanka and in pumice soils in Oregon (B.P. Warkentin, Oregon University, pers. comm., unpublished, 1988). In this Vertic Inceptisol, carbonate may also be involved as a cementing agent or by causing the chemical environment to be unfavourable for root growth. However, unless the nature of the carbonate changes between the C_1 and C_2 horizon, it seems unlikely to be involved because roots are able to grow in the C_2 horizon, in which carbonate levels are relatively high.

Further studies focussing on the upper levels of the C horizon are needed to define the root restriction mechanisms in this soil.

4.3 Remedial possibilities

It is probable that yield losses due to drought would be reduced if roots of (all) crops could grow into the C horizon. The upper part of the C horizon is an obvious target layer for disruption. If it could be broken up, the coarse physical composition should ensure that the fragments are relatively stable. Macropores created by the disruption should, therefore, be long lasting. Surface soil moving into the macropores would provide channels for root growth.

Where earthmoving equipment or powerful tractors are available, subsoiling implements can be used. Where such resources are not available, hand implements may be a slow but effective alternative. If the surface layer is excavated, the surface of the C horizon can be broken up with a pointed steel bar. Such excavation could be undertaken at intervals on the contour (trenching) to assist water conservation. Each season new trenches could be opened nearby, and the last season's trench refilled. In very shallow soils, it would not be necessary to excavate the top soil. An alternative to tillage would be to use aggressive rooting crops, such as castor, cowpea (*Vigna unguiculata* L.), or sunflower (*Helianthus annuus* L.), or perennial species, such as perennial pigeonpea (*Cajanus cajan* L.) or *Leucaena leucocephala* L., to pioneer root channels into the deeper layers.

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THE EFFECT OF ROOT/SHOOT RATIOS ON THE WATER RELATIONSHIP OF SORGHUM (Sorghum bicolor L Moench).

H. B. SO[1] and K. S. JAYASEKARA[2]
1. Department of Agriculture, University of Queensland, St Lucia, Qld 4067 (Australia) and 2. Coconut Research Institute, Lunuwila (Sri Lanka).

ABSTRACT

The proportion of roots initially required by two sorghum cultivars, E57 and Gem, to supply the demand for water by the canopy and their hydraulic characteristics were studied on plants grown in parallel split and serial split root systems under controlled environmental conditions. These systems enable good control of watering such that water uptake can be limited to specific sections of the root system.

Results from the parrallel split root systems show that cultivar E57 requires a smaller root system than Gem to meet the demand for water by a similar sized canopy. The ratio of root length/leaf area required were 5.8 and 8.8 cm/cm^2 for E57 and Gem respectively to maintain maximum transpiration rates. However, the average ratios were 8.0 (range 4.4 - 9.1) for E57 and 16.8 (range 11.8 - 20) cm/cm^2 for Gem to maintain maximum leaf water potentials. The associated resistances to water flow for the two cultivars under this system were measured as $(17.63 \pm 6.63) \times 10^{-5}$ h^{-1} and $(4.82 \pm 0.54) \times 10^{-5}$ h^{-1}.

Approximately similar ratios of root length/leaf area were required to maintain maximum transpiration rates and leaf water potentials in the serial split root system which simulates a drying soil profile. These ratios were 6.0 and 7.9 cm/cm^2 for E57 and 15.4 and 7.2 for Gem. The smaller size of root system required by E57 to maintain maximum transpiration is also associated with a higher resistance to water flow when the supply of water is adequate. However, when water is limiting (surface soil depleted), the resistance of E57 is lower than Gem due to a lower xylem resistance which gives E57 a greater ability to extract water from the deeper soil horizons.

It was concluded that E57 should be more tolerant to drought than Gem and this is consistent with experience in the field.

INTRODUCTION

It has often been stated that plants require extensive, well branched deep root systems for higher yields (Hurd, 1974; Nour & Wiebel, 1978) or that such root systems are essential features of drought resistant plants (Kramer, 1983). On the other hand, many studies have shown that the removal of a portion of the root system have no effect on growth on a variety of plants (Humphries, 1958; Meyer & Gingrich, 1964; Andrews & Newman, 1968; Downey & Mitchell, 1971; Tan et al. 1981 and Teskey et al.