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Root growth in Jatropha and its implications for drought adaptation

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ABSTRACT

The relative drought tolerance of *Jatropha curcas* is, so far, not very well understood. To understand its physiological adaptation to drought stress, the root growth viz; root length density (RLD), root dry weight (RDW), biomass accumulation and resources allocation for roots of adult trees grown in the field were assessed. The tap root in Jatropha branches perpendicular to the ground with many lateral roots. The rooting depth was 1.4 m with a greater root length distribution at the surface soil. It depicted a low root to plant ratio when the taproot was not included. The root branching in *Jatropha* suggested that it may help containing soil erosion although its contribution to drought tolerance is seemingly conservative. The drought response of *Jatropha* can be categorized as drought avoidance, considering its regular dormant state, drought-stress induced leaf drop and a limited root growth.

1. Introduction

J. curcas, a perennial shrub originating from Central America, is now being introduced to other tropical regions in Africa and Asia with a twin aim of biofuel production and rehabilitation of degraded lands. Jatropha is recommended for the tropics mainly because of its drought tolerance, non-edible nature for cattle, source of oil energy and a relatively high (950 kg ha^{-1} $year^{-1}$) C sequestration [1,2]. *J. curcas* has a minimum requirement of 300 mm rainfall per annum to survive, and 600 mm to bear fruits [3] but 944 mm under tropical savannah and monsoon climates for successful adaptation [4]. Water use assessment of *Jatropha* plantations in the semi-arid tropics at ICRISAT, India, indicated a monthly water use varying from 10 to 140 mm depending on crop phenophase, environmental demand and water availability [5].

J. curcas is believed to be relatively drought resistant while it mostly shows a drought avoidance strategy with expressions such as leaf shedding, high water use efficiency [6] and a likely low water footprint [7,8]. The water in the succulent stem was initially thought to play a role in regulating the predawn leaf water potential that was found to be high and uncorrelated with soil water potential [9-11]. However, recent understandings are that the stem water is reserved for the fresh leaf flushing as well as to keep these leaves active for several weeks after the start of the dry season [12,6]. The stem water was also found not to play a role in maximizing stomatal conductance, which is generally lower in Jatropha than that of co-occurring species and which decreases during the day [11,13].

Jatropha trees have unique root architecture as seen in seedling stage, comprising a thick strongly geotropic central taproot and four laterals [3] and this pattern of root structure in a adult had been expected to control soil erosion [4]. Patterns of soil water depletion by *Jatropha* on

Vertisols at ICRISAT, Patancheru indicated that the rooting front extension is slow, with the maximum depth of soil water extraction shown to increase only to 1.5 m on the fifth year from 1.0 m in the second year [5]. Structural and functional development of the root system has received very little attention so far. Excepting Maes et al., (6,7), no other study had dealt with the root-related strategies behind the high drought resistance of *J. curcas*. In this paper, we described the root growth, biomass accumulation and resources allocation for roots of *J. curcas* adult plants very broadly to address their physiological implications of drought adaptation.

2. Materials and methods

Root growth of *J. curcas* accession ICJC06101 was studied in a field trial at ICRISAT, Patancheru (17° 30' N; 78° 16' E; altitude 549 m) in peninsular India. The *J. curcas* was planted on 15 Jun 2006 in 1.5 x 1.5m spacing in a 0.3 ha Alfisol soil under regular irrigation in the first year to ensure uniform plant stand. These Alfisols were clayey-skeletal, mixed, isohyperthermic family of Udic Rhodustalfs with sandy clay loam to clay type, neutral soils with a CEC of 160 to 440 mmol kg^{-1} dry soil [14]. This soil contained layers of gravel (murrum) below 0.6 m.

One year-old plants were pruned at a shoot height of 0.6 m and irrigated thrice. After this the crop has grown rainfed. At sampling the plants were three years old and were ready to flower.

A 1.5 m wide and 2.5-m deep access trench, through the entire length of a row of *Jatropha* plants was dug using a backhoe digger (JCB excavator) for getting one side access for root extraction. Roots were extracted on 28 Oct 2009 from a 1.5 x 0.2 m area by a modified monolith method [15]. The soil blocks were sampled 0.15 m deep steel templates (0.3 x 0.2 m rectangular boxes open at the top and bottom) to maintain constant size of the sample. Similarly two more such samples of 0.3 m long adjacent area were covered on either side. A total of five samples were collected at each soil depth. To cover a whole strip of soil of single plant ground occupancy, sampling of all the soil in a 0.2 m strip for 1.5 m of plant spacing was conducted. The depths up to 2.1 m were covered with three replications. Soil samples containing roots were soaked in water overnight, soil was washed; root length was measured using an image analysis system (WinRhizo, Regent Instruments INC., Quebec, Canada) and dry weight measured after oven drying at 80° C till the weights became constant. This procedure has been clearly described in a chickpea root work [15].

Using the same access trench as above rooting depth and proliferation were measured after a mild washing of the wall with water. The wall surface, 0.75 m on either side of the plant base, was marked with grids 0.1 × 0.1 m using white nylon thread and metal pegs (Fig 1). The number of roots that were exposed in each grid was counted. This observation was non-replicated. For root anatomy assessment intact root tips > 0.1 m in length were selected and the portion of the root 0.1 m above the root tip was used. Free-hand transverse sections were made and stained in toludine blue solution (2 %) for 5 minutes. The sections were then washed thoroughly 5 times with distilled water and viewed under a light microscope.

The vegetative plant components weights were measured in three plants cut at the ground level and oven dried at 80° C till the weights became constant.

3. Results and discussion

The rainfall distribution, a year prior to sampling, was normal and the rainy events were approximately biweekly (Fig 2). In most plants the tap root branched into many primary branches and these branches tapered off within a short length into fine roots, producing horizontal shallow branches spreading on all sides (Fig.3A). The succulent thick root presence was limited to the plow pan. All the thicker roots are heavily spotted with dormant branch primordia (Fig.3B). The branching pattern has clearly shown dimorphism. Though limited, some of the distal roots at the last 0.10 to 0.15 m branched profusely and formed cluster roots with very short lengths of branches measuring 1 to 3 cm in length (Fig. 3C). A transverse section of the root, about 0.1 m above the root tip, showed a thick membrane like layer above the epidermis likely to be the protective cork (dead) layer. There was a well-defined cortex with large parenchymatous cells compressed centripetally (Fig 3D). These are mostly the water storage cells. The phloem is surrounded by two to three layers of laticiferous cells. The phloem tissue is limited and pushed to the periphery of the xylem. The xylem vessels were of assorted sizes with the protoxylem vessels in the centre and the growing metaxylem towards the periphery. The fully expanded large vessels were very few. The xylem fibres were absent explaining the soft nature of the wood. In general, the roots possessed more cortical parenchyma than the conducting tissues or stele.

The maximum rooting depth of Jatropha was 1.2 m (Fig. 4). But it was 1.4 m when assessed through trench wall method. The RLD distribution was the highest in 0.0-0.15 m soil depth measuring close to 5000 m m^{-3} (Fig. 4). However, this was reduced to 2000 m m^{-3} in the 15-30 soil layer and to <1000 m m^{-3} in 30-120 soil layers. Distribution of the highest RLD in the surface soils and the exponential decrease in RLD with the increase in soil depth was also confirmed through the trench wall method of sampling (data not shown). In wheat, an RLD greater than 0.5 cm cm^{-3} (5000 m m^{-3}) was estimated to be required for complete extraction of available soil water [16]. Though rooting depth and RLD need not necessarily reflect plant's ability to extract soil water, still an RLD of <1000 m m^{-3} can be safely concluded to be grossly suboptimal. But in terms of RDW distribution, the soil depth 0.0-0.30 m accounted for almost all the roots. In deeper soils below 0.30 m, the RDW reduced drastically. The rooting depth and the branching pattern observed here are in contradiction to previous reports [3] as four to five branches on a vertical tap root that was reported to penetrate up to 5 meters deep under Nicaraguan conditions. These contrasting expressions are likely due to the enormity in resilience of root growth under varying soil bulk density. In this field with Jatropha the red soil was heavy (bulk density >1.4 Mg m^{-3}), compact and shallow with an embedded murram layer after 0.60-0.75 m soil depth. However, one point is clear from these results that in heavy and dry soils the root system growth in *Jatropha* can also be shallow and poor as that of *Terminalia sericea* shrubs in the savannah of Namibia [17]

There was a clear and selective distribution of fine roots in the surface soil (0.00-0.15 m depth). The whole root system was divided into two groups; viz. fine (<0.5mm dia) and thicker roots (0.5 to 210 mm dia). The RLD of these very fine roots (Fig 5A) was about two times greater than that of the rest of the (thicker) roots (Fig 5B). Jatropha root system selectively produces greater lengths of fine root only in the surface soil similar to many of the Chihuahuan desert shrubs [18] that are likely to be helpful in utilizing scanty rainfall and to exploit relatively nutrient-rich surface of these marginal lands.

Estimations with the whole root system, the root/total plant ratio of Jatropha was 0.37. This is within the range reported by Achten et al. [19] on root/shoot ratio for 104 day old seedlings in different soil water deficit regimes (0.41 - 0.27). These values were the least when ten other tropical deciduous woody and shrub species were compared [19]. However, the root/ total plant ratio was reduced to a mere 0.03 when the tap root portion from 0 to 30 cm soil depth was not included, indicating that very little root biomass is devoted to absorption of soil moisture or nutrients. Jatropha produces much less root system to be ranked as a good producer under drought rather than good survivor.

Again, a low ratio of transpiration crop coefficients (0.51 to 0.60) compared to the reference crop [19] and a limited (0.51 – 0.70) stem sap flow ratio of adult plants [20,19] support the rating of conservative water use of Jatropha. The extent of leaf drop and timing is known to be acutely sensitive to the intensity of drought [6,19]. The retained leaves often exhibit parahelionasty as a drought response and change the anatomy of the new leaves to suit the low water availability. The plant is capable of a rapid adjustment to drought or escape drought well but not equipped for high productivity under drought. In another study, the poor genetic diversity observed in Jatropha originating from distant regions (Ethiopia, Thailand and India) lead to the conclusion that this plant is highly undomesticated. Maes et al. [7] had characterized this crop to have high relative growth rate and a greater TE while with lesser stomatal conductance and water use. They have also shown that this crop has evolved and adapted to plant survival under water-deficit environments rather than high level of plant productivity. Also these plants have a small SLA [7] and the presence of a limited number of narrow xylem vessels and a well defined cortex are indicative of potentially slow absorption of water. In order to take the right conclusions more research is necessary. Detailed information on the root system will elaborate the optimization of agro forestry and plantation systems.

4. Conclusion

The root system of Jatropha is shallow, the distribution sparse with a major RLD in the surface soil. The root system is dimorphic with a large network of fine roots distributed at the surface horizon. The proportion of biomass allocation was poor to the absorbing roots with a narrow and few xylem vessels enabling a slow uptake of water and nutrients. Based on these results and previous works, Jatropha can be described to follow a drought avoidance strategy with a conservative root system.

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Figures captions

Figure 1: (A) Root measurements in *Jatropha* using a trench wall method. The exposed wall is marked into 10×10 cm grids for root counts (B) the root intercepts within each grid.

Figure 2: Weekly rainfall quantities for one year prior to the root sampling.

Figure 3: (A) The root distribution in *Jatropha* at the top 0.5 m soil horizon. The roots were exposed using a trench wall, 0.15 m away from the tap root, and the plant base was exposed later by washing the soil away through a water hose. Notice the loss of tap root dominance, the profuse branching at the plow pan level and the lack of any further thicker roots approximately below 0.3 m soil depth. (B) A close up of a small length of the primary root showing further branching as well as large number of branch primordia, the root is split open to show the low density soft wood. (C) Cluster roots : A close up view of some of the dug roots that had shown cluster root morphology, an expression considered as an adaptation to poor nutrient, particularly P, status of the soil. (D) The transverse section of the roots of *Jatropha*, 0.1 m anterior to the root tip, showing low number of assorted size of xylem vessels with no xylem fibers (magnified 40 × 10).

Figure 4: The root distribution in *Jatropha* as measured through a monolith method. Changes in (A) root length density across various soil depths and (B) in root dry weight across various soil depths in a three year-old plant. Such a large difference in distribution weight or length is primarily caused by the small section of tap root at the 0.0-0.30 m soil horizon.

Figure 5: Root length density (m m^{-3} of soil) distribution of the (A) fine roots (<0.5 mm thick) and (B) relatively thicker roots (>0.5 to 215 mm thick) at the plant base (central horizontal bar in each depth), 30 cm away from the plant base on either side (the second and fourth bar from the

top) and 0.6 cm away from the plant base on either side (the top and the bottom bars) of 3 year-old *Jatropha* plants.

Figure 1

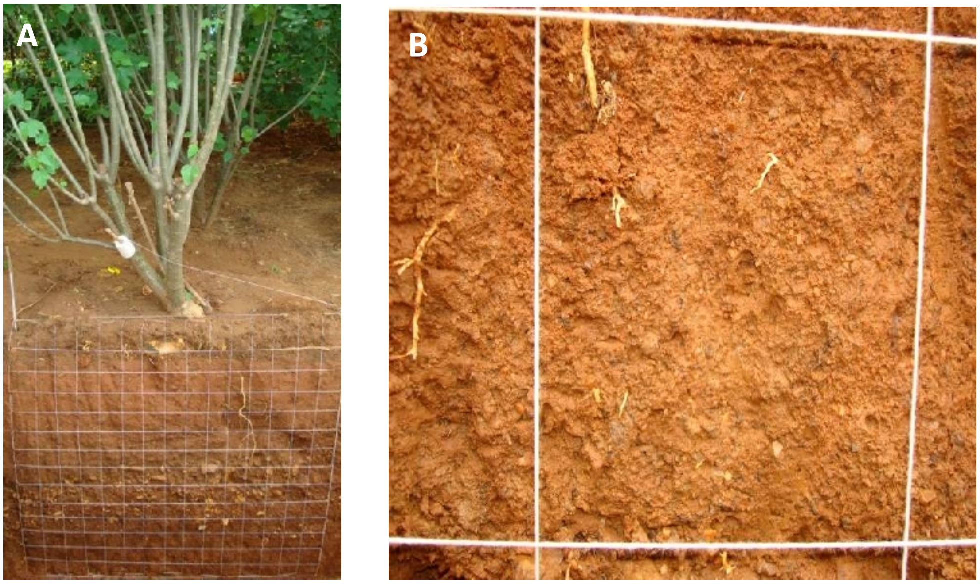
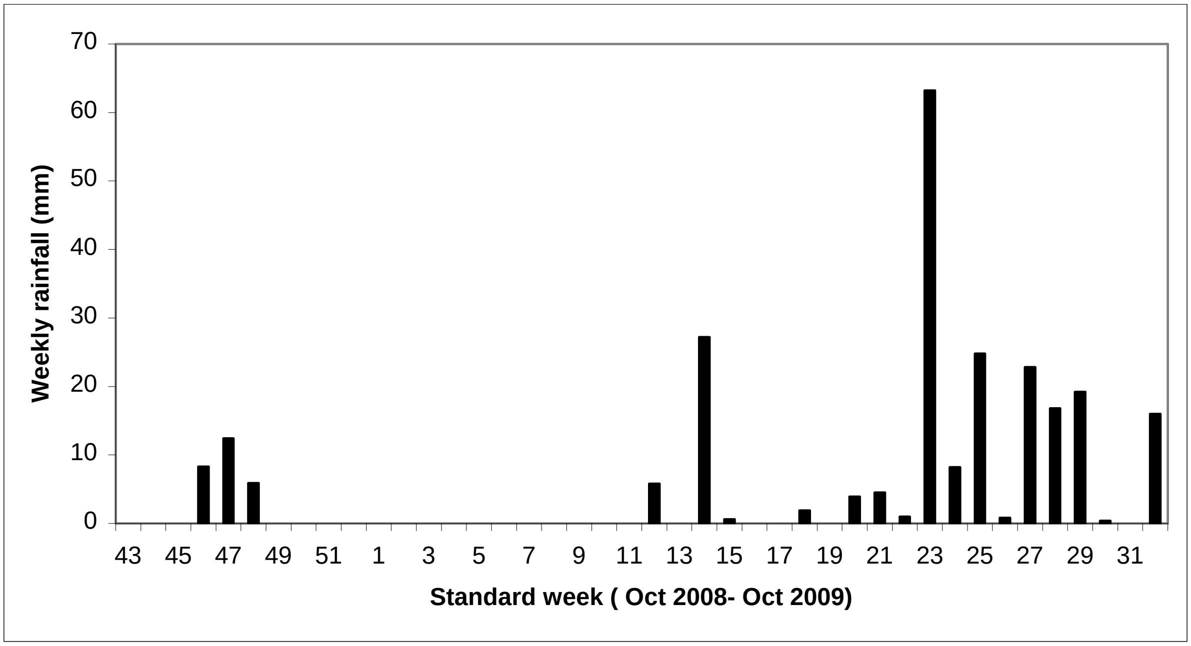


Figure 2.



Weekly rainfall (mm)
70
60
50
40
30
20
10
0
43
45
47
49
51
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
Standard week (Oct 2008- Oct 2009)

Figure 3

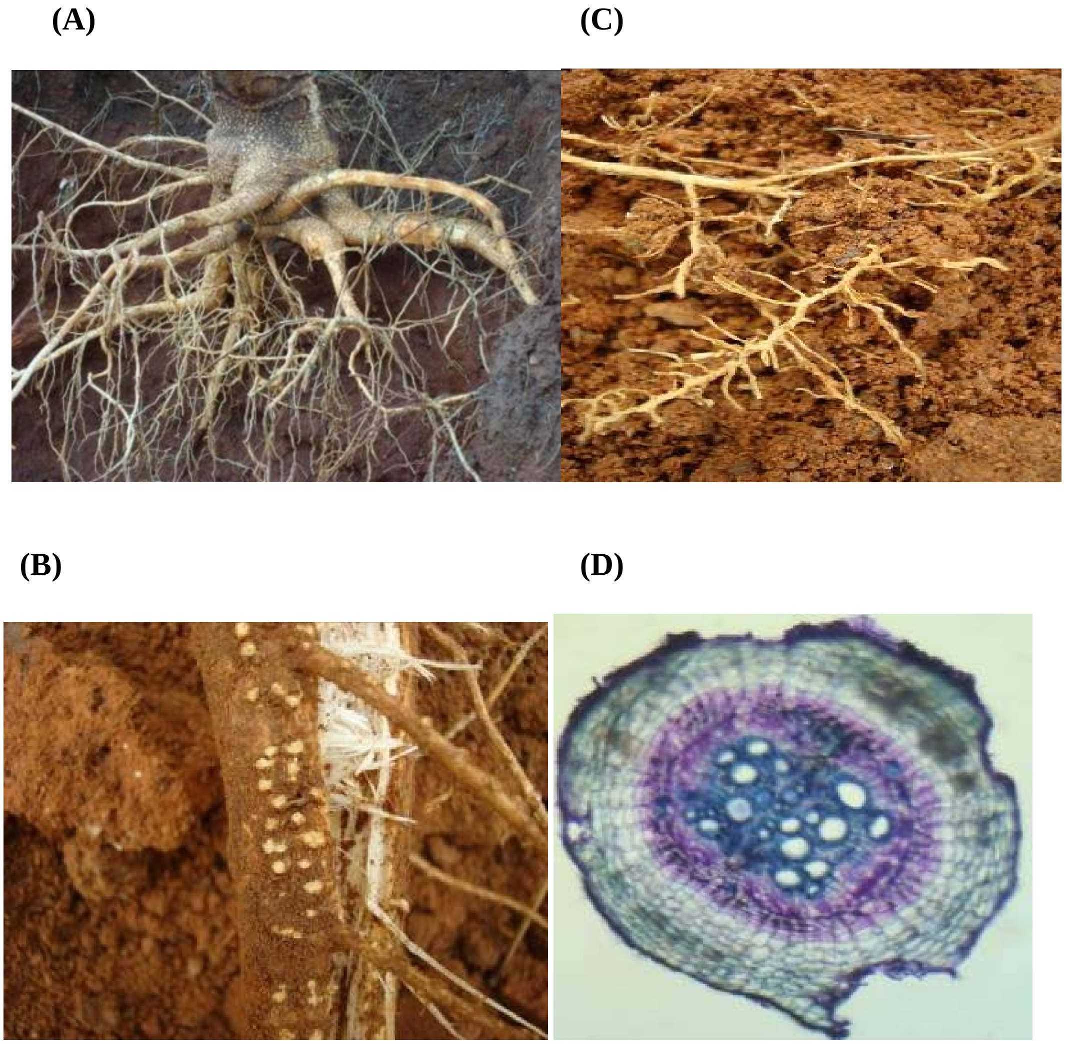


Figure 4

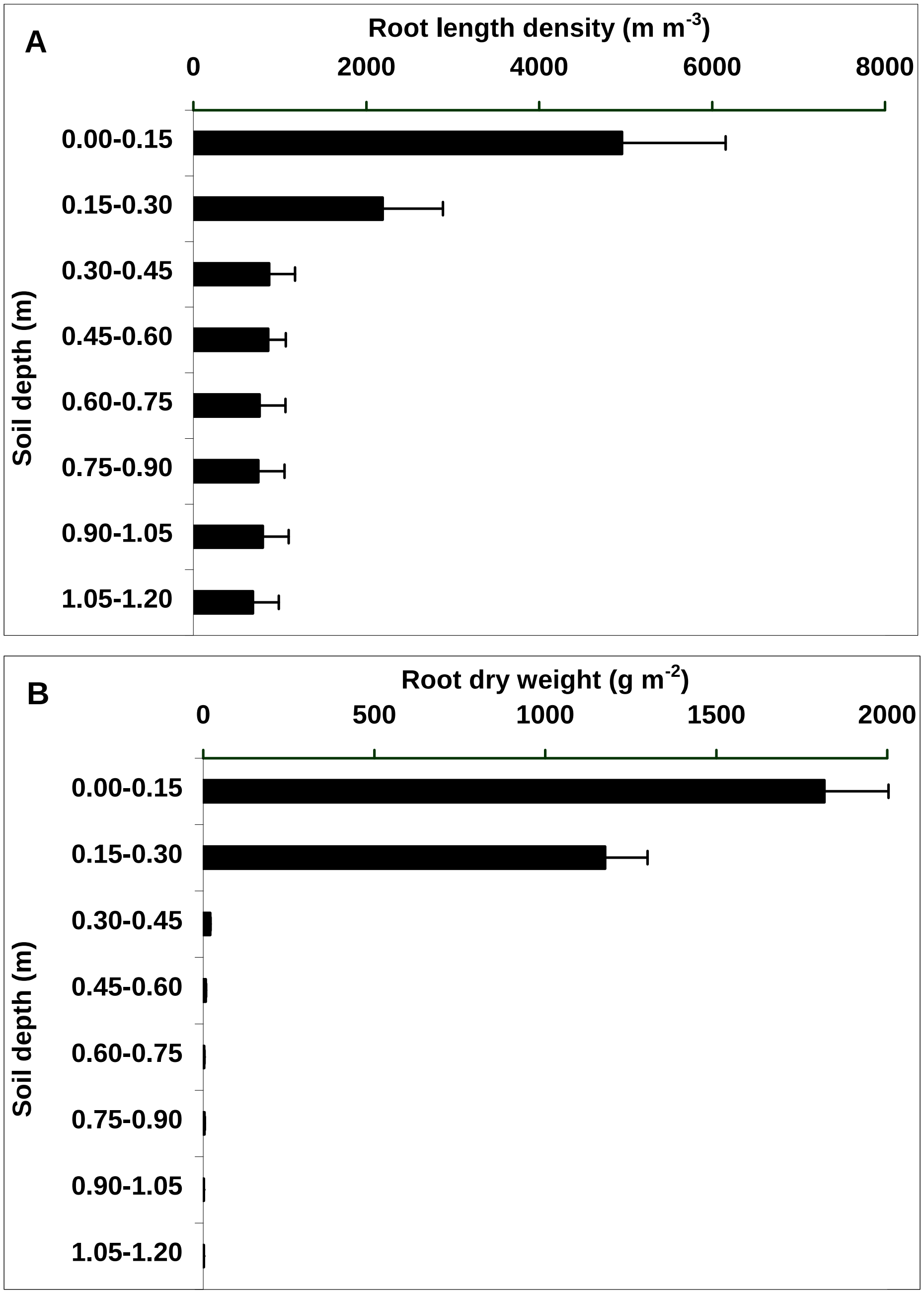
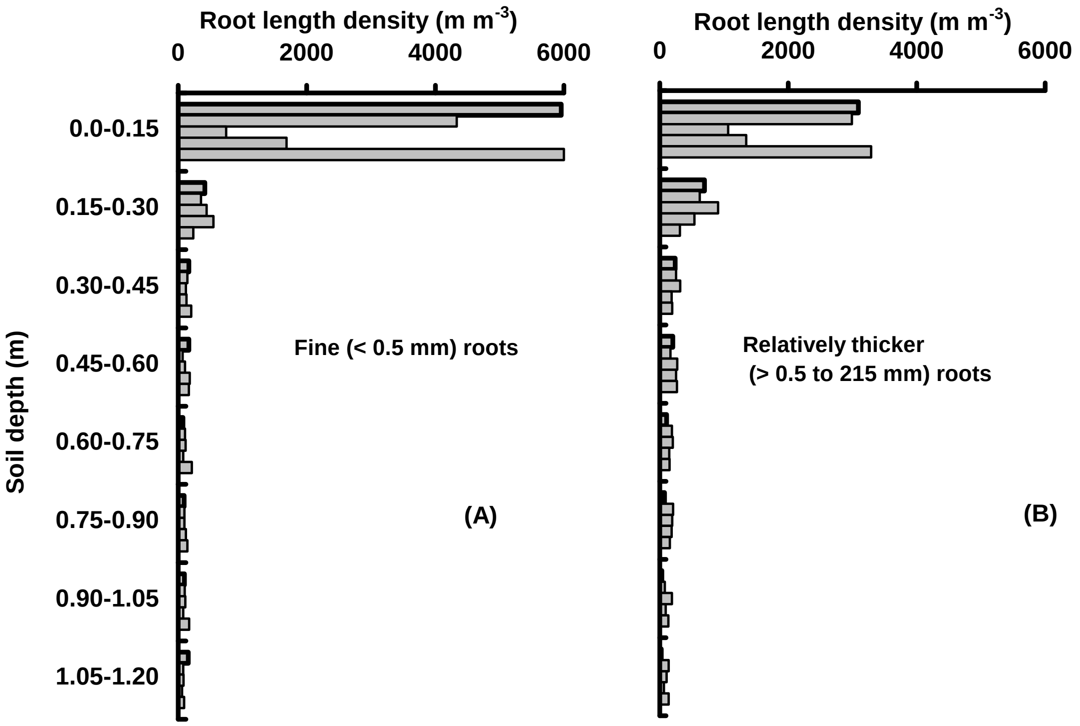

A
Root length density (m m-3)
0
2000
4000
6000
8000
Soil depth (m)
0.00-0.15
0.15-0.30
0.30-0.45
0.45-0.60
0.60-0.75
0.75-0.90
0.90-1.05
1.05-1.20
B
Root dry weight (g m-2)
0
500
1000
1500
2000
Soil depth (m)
0.00-0.15
0.15-0.30
0.30-0.45
0.45-0.60
0.60-0.75
0.75-0.90
0.90-1.05
1.05-1.20

Figure 5


Root length density (m m-3)
0
2000
4000
6000
Root length density (m m-3)
0
2000
4000
6000
Soil depth (m)
0.0-0.15
0.15-0.30
0.30-0.45
0.45-0.60
0.60-0.75
0.75-0.90
0.90-1.05
1.05-1.20
Fine (< 0.5 mm) roots
(A)
Relatively thicker
(> 0.5 to 215 mm) roots
(B)