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Fibrous root distribution in pineapple orange trees under semi-arid irrigated ecosystem

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Key words: Cleopatra (*Citrus reshni*), depth, radial distance, root excavation, root length density, rootstocks, Rough lemon (*Citrus jambhiri* Lush), Troyer citrange (*Poncirous trifoliate* x *Citrus sinensis* Osbeck).

Abstract: The root distribution pattern of 17-year-old pineapple orange trees budded on Rough lemon, Cleopatra and Troyer citrange rootstocks were studied by root excavation method at four radial distances, 0-75, 75-150, 150-225 and 225-300 cm from tree trunk, and at three depths, 0-15, 15-30 and 30-60 cm. Fibrous root length density (FRLD) and fibrous root length percentage differed significantly at various depths and radial distances among rootstocks. FRLD was closer to tree trunk on both horizontal and vertical planes. Root density decreased from 0.183 to 0.084, 1.051 to 0.238 and 0.238 to 0.095 cm.cm^{-3} from 0-15 cm to 30-60 cm depth within 0-75 cm radial distances from tree trunk in trees on Rough lemon, Cleopatra and Troyer citrange, respectively. Cleopatra contains the highest 0.231 cm.cm^{-3} FRLD as compared to 0.051 cm.cm^{-3} in Rough lemon and Troyer citrange. Troyer citrange has intensive lateral root development with 84% fibrous roots (FR) within 75 cm radial distance, whereas Rough lemon and Troyer has an appreciable amount up to 225 cm distance (extensive lateral). Cleopatra contained 57% FR in upper soil layer (0-15 cm) (intensive vertical). In Rough lemon and Troyer 54% FR are confined to lower depth 15-60 cm (extensive vertical root development). Troyer and Rough lemon had the same vertical, whereas Rough lemon and Cleopatra showed the same horizontal rooting pattern under arid irrigated ecosystem. Thus, irrigation depth and fertilizer placement should be critically rootstock specific.

1. Introduction

Citrus production depends not only upon soil, climate and high density planting but also rootstocks play an important role as different rootstocks have different intensities of root proliferation and penetration (Castle and Krezdorn, 1975; Neves *et al*., 2004; Morgan *et al*., 2007). Moreover, roots are the principal organ for absorption of nutrients and water from soil. Root system structure determines the volume of the soil accessible to the crop plant and it is important to maintain sufficient water and nutrient concentration within the soil occupied by the crop root system for optimal nutrient and water uptake (Kramer and Boyer, 1995; Scholberg *et al.,* 2002). Increasing the density of fibrous root within a crop root system increases the amount of water and nutrients available to the crop (Eissenstat *et al.,* 1999; Tinker and Nye, 2000).

The rootstock in turn can be influenced by the scion and soil environment. Performance of rootstock in a certain environment is related to total volume, configuration, lateral distribution and depth of the root system (Cintra *et al.,* 1999). The root distribution pattern of a tree varies from region to region and from one rootstock-scion combination to another. Even a single rootstock-scion combination may differ in root distribution with a change in climatic condition. Mikhail and El-Zefhoui (1979) found that 79% of the total fibrous root of Valencia orange occurred in the first 60 cm of soil depth on sandy soil, whereas clay soil contained 94% in the same depth. Boman *et al*. (1999) reported that citrus production in deep sandy soils with a high volume irrigation system tends to cause the upper soil layer to dry out between long irrigation intervals and this condition favours deep rooting. Hipondoka *et al*. (2003) reported that most of the root activities in trees with regard to water uptake are performed near the soil surface in arid ecosystems of Africa. These differences in rooting pattern among rootstocks and soil environments are more likely to reflect the adaptation of plants to a given environment.

Since citrus growth and root distribution system is rootstock-dependent and may be modified as a result of changes in the root environment, a clear understanding of the root system is important to best deal with management practices such as irrigation and nutrient application and fixing the geometry in a particular ecosystem. Keeping in mind the above facts, the present investigation was carried out with the objectives to

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determine the rooting pattern of 17-year-old Pineapple orange budded on three rootstocks under an arid ecosystem of Punjab (India).

2. Materials and Methods

Study sites

The trial was conducted at the experimental orchard of the Punjab Agricultural University, Regional station, Bathinda located at 211 m above mean sea level, latitude 74° 58' E and longitude 30° 17', and average rainfall 400 mm/year. However 80% of the rainfall is received during the Southwest monsoon season (first week of July to mid September). The mean maximum temperature is 40-45°C in June with hot winds and minimum temperature is 4-5°C in January.

Soil characteristics

The soil samples collected from the experimental orchard at a depth of 0-30 cm were analysed for their physical and chemical properties. The soil type was loamy sand with clay content 13%, bulk density 1.5g/cc with moisture holding capacity of 40-45%, moisture at field capacity 25-28%. The pH of the site was 8.32 with electrical conductivity (EC) 0.2 dsm^{-1} and calcium carbonate 5-12%. The available N, P, K contents were 160-182, 13-17 and 320-346 Kg/ha, respectively.

Treatments

Mature pineapple orange trees budded on three rootstocks, i.e. Rough lemon (*Citrus jambhiri* Lush), Cleopatra (*Citrus reshni*) and Troyer citrange (*Poncirous trifoliate* x *Citrus sinensis* Osbeck), at a spacing of 6x6 m planted in 1990 were selected for the study. All three sets of five mature 17-year-old trees were grown under uniform cultural practices (i.e. irrigation with flooding); fertilizer application at 880 g Nitrogen and 440 g. Phosphorus/plant/year and mechanical weeding/hoeing were selected randomly in a randomized block design and examined for the root distribution system.

Sample collection

For each plant a circle with a radius of 3 m from the tree trunk was marked. This radius was further divided into four segments with 0-75, 75-150,150-225 and 225-300 cm radius. The circle circumference was divided into eight parts and one-eighth sections were excavated at three depths, viz. 0-15, 15-30 and 30-60 cm (Fig. 1). The roots of 15 plants were excavated with a jet of water at a pressure of 10-15 psi. The plants were exposed to a radial distance of 3 m from the trunk and down to a depth of 15 cm from the ground surface; exposed roots were painted red. The roots were then excavated to a depth of 30 cm (i.e. between 15-30 cm) and exposed roots were painted yellow. The roots were further excavated to a depth of 60 cm (i.e. between 30-60 cm) and these roots were kept as such to distinguish them from other roots. After the entire root system was exposed, the roots were collected from each segment of depth and radial distance separately and washed. The root diameter was measured with the aid of a vernier caliper and those having diameter < 0.2 cm were categorized as fibrous roots. The fibrous root length of each segment was measured using a meter scale separately.

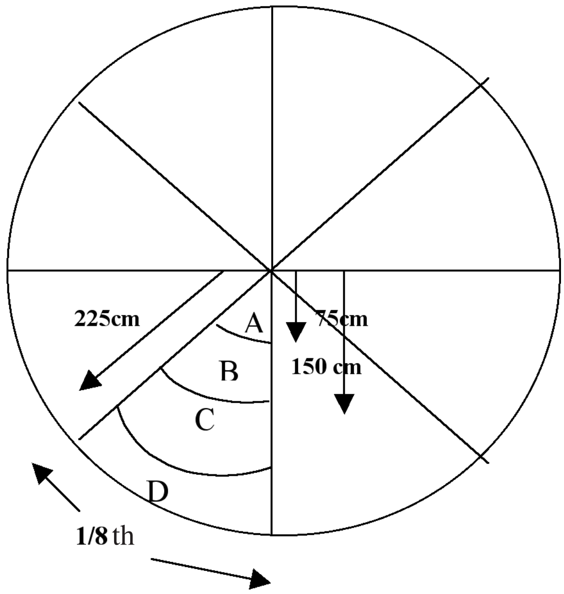

Fig. 1 - Scheme of the root sampling areas around the trunk (radial distances: A = 0-75 cm; B = 75-150 cm; C = 150-225 cm; D = 225-300 cm).

Data collection

We estimated root length per soil volume represented by the volume of soil calculated as the radial distance from the trunk by the depth increment (0-15; 15-30; 30-60 cm) for each of the 15 orange trees. The surface area of the ring of radial distance 0-75 cm (A) was determined by calculating the area of a circle with radius of 75 cm. The area of ring between radial distances 75-150 cm (B) was equal to the area of a circle with a radius of 150 cm minus the area of ring A. Similarly the areas of the other rings (C and D) were determined by subtracting consecutively the area of the adjacent smaller circle from the larger one. The volume of soil used to determine the estimated root length at each sampling location was the product of the area of each ring determined by the sampling distance and soil depth (0-15, 15-30 and 30-60 cm) then divided by 8 because only one-eighth of each ring was excavated. Fibrous root length density (FRLD) was determined by dividing the sample fibrous root length for each sampling location by their respective sample soil volume and expressed as $cm\ cm^{-3}$.

The root length percentage at various depth zones and radial distances from tree trunk was determined on the basis of total root length, irrespective of radial distance and depth respectively.

Statistical analysis

The experiment was set up in randomized block design with three sets and five replications. The FRLD and root length percentage of the three rootstocks at various depths and radial distances from the trunk were analysed by one-way ANOVA using Duncan's multiple range test ($P < 0.05$).

3. Results

Fibrous root length density (FRLD) was significantly different among the rootstocks. Therefore the FRLDs were pooled and analysed for interaction among rootstocks, soil depths and distances from tree trunk. Although the average FRLD to a 60-cm depth was statistically significant for Cleopatra (0.231 $cm.cm^{-3}$) in respect to Rough lemon (0.048 $cm.cm^{-3}$) and Troyer citrange (0.051 $cm.cm^{-3}$) which were otherwise at par (Table 1). A significant interaction of rootstock and depth suggests distinctly different root distribution patterns among the three rootstocks. Trees on Cleopatra had significantly greater FRLD than trees on Rough lemon and Troyer citrange, whereas the FRLD was not statistically significant between Rough lemon and Troyer citrange at all soil depths. FRLDs decreased significantly with every increase in soil depth in Rough lemon and Cleopatra, whereas with Troyer citrange FRLD was at par between 0-15 and 15-30 cm depth. The maximum FRLDs (0.067, 0.390 and 0.070 $cm.cm^{-3}$) were observed in the top 15-cm soil layer in Rough lemon, Cleopatra and Troyer citrange, respectively. A high proportion of fibrous root length (FRL) was found in the upper 0-15 cm soil containing 46, 57 and 45% of Rough lemon, Cleopatra and Troyer citrange, respectively, which also did not differ significantly. The proportion of FRL differed significantly with every increase in soil depth in Rough lemon and Cleopatra and at par in Troyer citrange at 0-15 and 15-30 cm depth. However trees grown on Rough lemon and Troyer citrange have more FRL (57%) deeper than 15 cm compared with trees grown on Cleopatra (43%), resulting in only 45% of Rough lemon and Troyer citrange root length at more than 15 cm depth. FRLD and percentage root length of Cleopatra differed significantly compared to Rough lemon and Troyer citrange at all depth zones, whereas Rough lemon and Troyer citrange were not significantly different.

Unlike soil depth, distance from trunk had more effect on distribution of fibrous roots among rootstocks (Table 2). Cleopatra had significantly greater FRLD at all 75-cm increments in radial distances from trunk in respect to Rough lemon and Troyer citrange rootstocks. Troyer citrange showed significantly more FRLD (0.173 $cm.cm^{-3}$) compared to Rough lemon (0.129 $cm.cm^{-3}$) at the 0-75 cm radial distance, whereas for greater radial distances, Rough lemon contained significantly more FRLD compared to Troyer citrange. FRLDs differed significantly with every increase in radial distance in Rough lemon and Cleopatra while in Troyer FRLDs at 75-150 and 150-225 cm radial distances did not differ significantly. The highest proportion of FRL was observed close to the trunk (i.e. 0-75 cm radial distance from trunk) in all the rootstocks. However, Troyer citrange showed maximum FRL (84%) within 75 cm radial distance whereas, trees

Table 1 - Pineapple orange tree mean fibrous root length density (FRLD) and percentage of root length in the radial distance up to 300 cm of the soil for rootstock and soil depth

Soil depths (cm)	Rough lemon		Cleopatra		Troyer citrange	
	FRLD ($cm.cm^{-3}$)	Root length 0-60cm (%)	FRLD ($cm.cm^{-3}$)	Root length 0-60cm (%)	FRLD ($cm.cm^{-3}$)	Root length 0-60 cm (%)
0-15	0.067 a	46.19 a	0.390 a	57.02 a	0.070 a	45.11 a
15-30	0.048 b	33.24 b	0.210 b	29.39 b	0.057 a	36.74 a
30-60	0.030 c	20.56 c	0.093 c	13.59 c	0.028 b	17.88 b
Average	0.048		0.231		0.052	

Fibrous root length density (FRLD) and root length (%) separation by Duncan's multiple range tests. Values followed by different letter within a column are significantly different (< 0.05) from other values in the same column. Mean (n=5).

Table 2 - Pineapple orange tree mean fibrous root length density (FRLD) and percentage of root length in the upper 60 cm of soil for rootstock and distance from the tree trunk

Radial distances (cm)	Rough lemon		Cleopatra		Troyer citrange	
	FRLD ($cm.cm^{-3}$)	Root length 0-300 cm (%)	FRLD ($cm.cm^{-3}$)	Root length 0-300 cm (%)	FRLD ($cm.cm^{-3}$)	Root length 0-300 cm (%)
0-75	0.129 a	66.54 a	0.642 a	70.31 a	0.173 a	84.20 a
75-150	0.031 b	15.87 b	0.139 b	15.23 b	0.017 b	8.26 b
150-225	0.022 c	11.39 c	0.097 c	10.58 c	0.011 bc	5.37 bc
225-300	0.012 d	6.19 d	0.035 d	3.87 d	0.004 c	2.15 c

Fibrous root length density (FRLD) and root length (%) separation by Duncan's multiple range tests. Values followed by different letter within a column are significantly different (< 0.05) from other values in the same column. Mean (n=5).

grown on Rough lemon and Cleopatra, showed 82-85% of FRL within 150 cm radial distance. The proportion of FRL beyond 75 cm radial distance was for Rough lemon and Cleopatra at par and significantly more than Troyer citrange. All rootstocks differed significantly for FRLD with every increment in radial distance, but Cleopatra and Rough lemon did not significantly differ in root length percentage and differ significantly compared to Troyer citrange.

However, the greatest FRLD in the top 15-cm depth ranged from 0.08 to 1.05 cm.cm^{-3} soil at a distance of 300 cm or less for trees on Cleopatra, whereas FRLDs ranged from 0.016 to 0.183 and 0.006 to 0.238 cm.cm^{-3} at the same depth and distance from trees on Rough lemon and Troyer citrange, respectively (Fig. 2). The figure illustrates that the fibrous roots are concentrated closer to the tree trunk (i.e. up to 75 cm radial distance and 0-15 cm depth). Beyond the radial distance of 75 cm there was a very sharp decrease in FRLDs in all rootstocks. The effect is more pronounced in Troyer citrange at 0-60 cm depth, followed by Cleopatra (15-60 cm) and Rough lemon (30-60 cm).

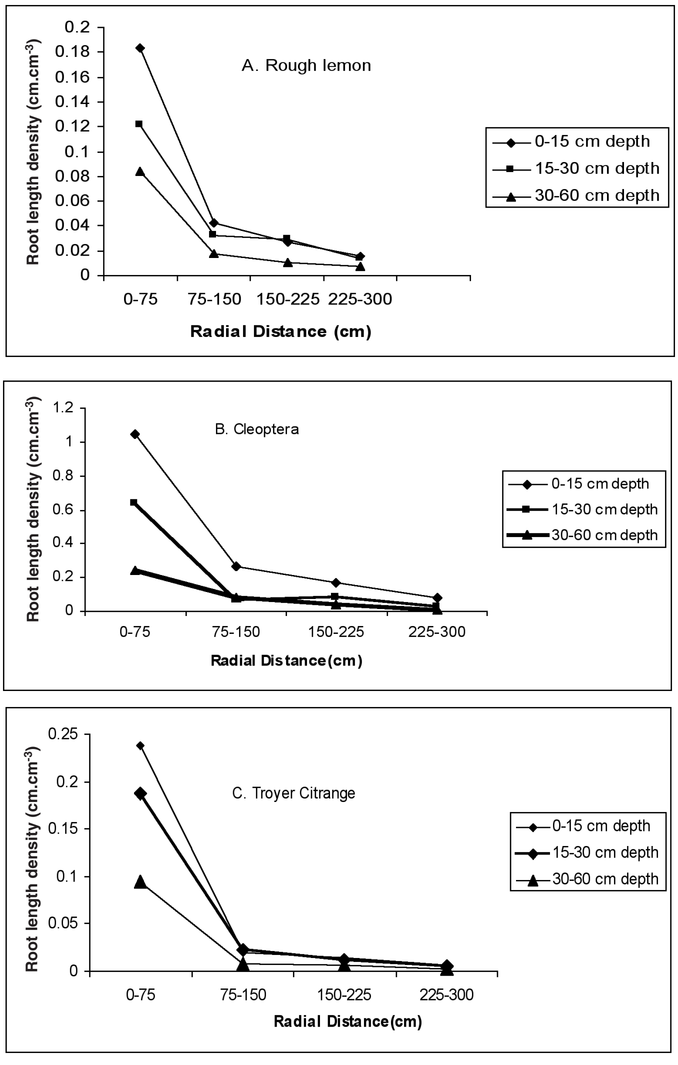

Fig. 2 - Changes in fibrous root length density as a function of soil depth from the surface and radial distance from the tree trunk for pineapple orange trees on (A) Rough lemon (n=5); (B) Cleopatra (n=5) and (C) Troyer citrange (n=5) rootstock.

4. Discussions and Conclusions

Fibrous root density was influenced by depth and distance from trunk and rootstock. However, fibrous root length observed was lower than earlier reports (Kaufman *et al.*, 1972; Castle, 1980; Morgan *et al.*, 2007) which may be due to sampling time in late spring because in citrus root growth is periodic; root activity declines during fall/winter with unfavourable environment and moisture stress condition then a spring growth flush takes place. Root activity then increases immediately after the cessation of shoot elongation in summer months. There is a gradual decrease in FRLD with depth and distance from tree trunk. However the FRLD's were highest near the surface and closer to trunk in all rootstocks (Castle, 1980; Kurien *et al.,* 1991; Swietlik, 1992; Zhang *et al.,* 1996). Cleopatra had more overall fibrous root length compared to Rough lemon and Troyer citrange, the latter which showed the same intensity. This may be due to differences in their rooting pattern or genetic make-up.

Cleopatra had more roots (57%) in the upper layer (0-15 cm) compared to Rough lemon and Troyer citrange (45% each), however Cleopatra rootstock showed only 42% fibrous roots between 15-60 cm while Rough lemon and Troyer citrange contained 54%. Hence Cleopatra may be classified as shallow rooted. Thakur *et al.* (1981) concluded that citrus is basically a surface feeder. Similarly, Avilan *et al.* (1985) reported that most Cleopatra roots (80%) were located in the top 30 cm of soil under the canopy of the tree. Similar results were reported previously by Zhang *et al.* (1996): root density was greater (75%) at 0-15 cm depth when field is flooded and nitrogen is spread and less than 10% at 30-60 cm depth in grapefruit on sour orange. Neves *et al.* (2004) found that 80% of the roots grow under 31 cm for African rough lemon and more root area was observed at lower horizon of the soil in P. trifoliata and C13 citrange as compared to Rough lemon and Sunki mandarin for Tahiti lime. Sharma and Chauhan (2005) found in apple nearly all fibrous roots above the 50 cm depth with very few roots between 75-100 cm.

Troyer citrange showed 84% fibrous root closer to tree trunk (0-75 cm) and at higher distance there was a very sharp decrease showing less than 10% at 75-150 cm distance, whereas, Rough lemon and Cleopatra has 82-85% FR within 150 cm radial distance with less than 10% fibrous root length beyond 225 cm. Thus Troyer citrange has an intensive lateral root development and Cleopatra and Rough lemon showed an extensive lateral root system. The maximum root growth in citrus takes place during summer months following rainy season, hence this may cause more lateral and less vertical root development due to the availability of water in the upper layer during active root growth period. In arid climates, higher root density are in irrigated compared to non-irrigated zones and effect of irrigation is closer to tree trunk due to shading effect or lower evaporation under the canopy (Bielorai, 1985; Roth and Gardner, 1985; Morshet *et al.,* 1989). Furthermore, Rough lemon and Cleopatra have a dense and large canopy in comparison to Troyer citrange, hence the dense and large canopy reduced soil water losses by evaporation forming a favourable environment for root development in the upper layer. Secondly, the largest part of roots are formed within the 0-15 cm depth, the most important layer for plant nutrient supply specially, phosphorus that stimulates root growth in layer fertilized with nutrients. Troyer citrange showed a reduced and somewhat upright growth of canopy hence more moisture loss under the canopy took place which make roots to divert to lower horizon for water uptake. These results are in accordance with those of Misra *et al*. (2003) in grape fruit budded on trifoliate orange. Carrizo citrange rootstock has intensive type root system and less lateral development in Hamlin rootstock (Castle and Krezdorn, 1975; Morgan *et al.,* 2007). Similarly Castle (1980) and Cintra *et al*. (1999, 2000) found that Rough lemon and Cleopatra have large root system and rough lemon extensive lateral and vertical development. Kurien *et al*. (1991) reported that most root activity (75-80%) was confined within a radius of 80 cm and 24 cm in depth in acid lime on karna khatta (*Citrus karna*)

In this study, we have observed that FRLD distribution of pineapple orange trees grown on Rough lemon, Cleopatra and Troyer citrange rootstocks decreased with soil depths and lateral distances. The overall maximum FRLD was recorded in Cleopatra at all the depths and radial distances. The density of feeder roots was concentrated at a depth of 0-15 cm within 75 cm radial distance. Trees grown on Troyer citrange and Rough lemon showed an appreciable amount of FR up to 60 cm in depth and may be classified as plants with an extensive vertical root development, whereas, in Cleopatra and Rough lemon a noticeable amount of FR is confined up to 225 cm radial distance and hence can be considered as extensive lateral development. Trees on Troyer citrange have FR very closer to tree trunk (0-75 cm) i.e. intensive lateral roots. Cleopatra showed more roots in the upper soil layer (0-15 cm) and it can be considered as upper intensive root development. Therefore depth of irrigation and placement of fertilizer based on root distribution should be rootstock specific and deep ploughing should be avoided.

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