GRAPEVINE ROOT DISTRIBUTION IN DRIP AND MICROSPRINKLER IRRIGATION

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ABSTRACT: Grape (*Vitis vinifera* L.) yield and its quality are dependent of the status of the root system. Root distribution information is also valuable for soil and water management. An analysis of methods to evaluate the root distribution of grapevines for both, drip and microsprinkler irrigation in a Typic Acrustox is presented for the table grape cv. Italia grafted on the rootstock IAC-313, in northeastern Brazil. Measured root parameters using the monolith method were root dry weight (D_w) and root length density (L_v), while root area (A_p) was estimated using the soil profile method in combination with digital image analysis. For both irrigation systems, roots were present to the 1 m soil depth and extended laterally to 1 m distance from the trunk, but grapevines irrigated by microsprinkler showed greater root presence as the distance from the trunk increased. Values of A_p were reasonably well correlated to D_w and L_v. However, correlation values were higher when fractional root distribution was used. The soil profile method in combination with image analysis techniques, allows proper grapevine root distribution evaluation.
Key words: *Vitis vinifera* L., root system, digital image

DISTRIBUIÇÃO RADICULAR DE VIDEIRAS IRRIGADAS POR GOTEJAMENTO E MICROASPERSÃO

RESUMO: A produção de uva (*Vitis vinifera* L.) em termos quantitativos e qualitativos depende do estado das raízes. Além disso, informações sobre a distribuição radicular são úteis para o manejo de solo e água. Por isso, uma análise de métodos para a avaliação da distribuição radicular de videiras cv. Itália / IAC 313 num Latossolo Vermelho Amarelo irrigadas por gotejamento e microaspersão foi realizada em Petrolina – PE e Juazeiro - BA, no Vale do São Francisco. Os parâmetros medidos pelo método do monolito foram a matéria seca (D_w) e densidade de comprimento de raízes (L_v), enquanto a área de raízes (A_p) foi estimada pelo método do perfil de solo combinado com a análise de imagens digitais. Para ambos os sistemas de irrigação, as raízes estiveram presentes até 1 m de profundidade e estenderam-se lateralmente até 1 m de distância do tronco, mas as videiras irrigadas por microaspersão apresentaram uma maior presença de raízes com o aumento da distância do tronco. Os valores de A_p apresentaram uma boa correlação com D_w e L_v, mas essa correlação foi maior quando se utilizou a distribuição fracional de cada parâmetro. O método do perfil auxiliado pela análise de imagem digital permite a avaliação da distribuição radicular.
Palavras-chave: *Vitis vinifera* L., raízes, imagem digital

INTRODUCTION

The root system serves important physiological and biochemical functions, and it has been shown that both grape yield and quality are dependent on the health status of the roots (Morlat & Jaquet, 1993). Many soil and management factors, such as temperature, mechanical resistance, aeration, texture, water and nutrient availability, pH, frequency and depth of tillage, mulching and organic matter content, affect root distribution of grapevines (Kirchhof et al., 1991; Morlat & Jaquet, 1993; Richards, 1983). In addition, root functionality is variable and depends on the grapevine cultivar or rootstock (Perry et al., 1983; Nagarajah, 1987; Morano & Kliewer, 1994). Regarding water supply to roots, the type of irrigation system has been shown to affect root distribution (Morano & Kliewer, 1994) as influenced by irrigation frequency, soil water availability, and spatial distribution of water and nutrients (Araujo et al., 1995; Clothier & Green, 1997; van Zyl, 1988). Moreover, actual root water uptake not only depends on root distribution and its functioning, but also on soil water availability and salinity. In addition to water stress in periods of low water availability, root water uptake is also reduced when concentrations of soluble salts exceed plant-specific threshold values (Homaee, 1999). In irrigated soils, particularly in arid and semi-arid regions, plants are generally exposed to both, salinity and water stress. In these regions, soil and water management practices are based on maintaining a favorable soil water content and salinity status in the root zone, thereby minimizing periods of water stress while controlling leaching to minimize salinity stress. Furthermore, there is an increasing interest in the influence of soil water stress on grape and wine qualities (Bravdo & Hepner, 1987; Freeman, 1990; Matthews & Anderson, 1988; Myburgh, 1994; van Zyl & van Huyssteen, 1984). These issues, in combination, justify studying the interrelationships between irrigation water management, root distribution grape, yield and quality.

Grapevine root growth initiates after bud burst and growth rates increase rapidly to a maximum at the blooming stage, after which the growth rate decreases. However, a new growth period starts after harvest (van Zyl, 1988). Depending on age, structural roots vary in diameter but are usually between 6-100 mm. From the main framework, smaller permanent roots (diameter 2-6 mm) arise and grow either horizontally or vertically. These roots extend and branch in a few main extension roots that are generally thin (diameter 1-2 mm) and grow rapidly. These finer roots die within weeks after emergence but are replaced continuously (Richards, 1983).

Root distribution refers to the presence of roots within a fixed grid. Typically, root distribution studies include root biomass or root length as a function of soil depth, distance from the plant stem, and position between neighboring plants. Measurement of root distribution in agricultural communities often includes roots of more than one plant. Root architecture refers to the spatial configuration of the root system, specifically focusing on the geometric properties of root axes and laterals, mostly concerned with the entire root system characteristics (Lynch, 1995). Image analysis may provide all required information on root distribution and architecture, allowing for an explicit characterization of water and nutrient exploration, comparisons between plant cultivars and soil and water management practices.

Root analysis as a tool to study root behavior may benefit from using a combination of various measurement methods (Atkinson, 1980). Although root distribution analysis by the monolith method is difficult, laborious and time-consuming (Bohm, 1979), it provides detailed information on root length and diameter within a soil profile. Despite the fact that finer roots are more likely involved in plant water uptake, evidence has been presented that the larger suberized roots can also be effective in water and nutrient acquisition (Kozinka, 1991; van Zyl, 1988). However, because of uncertainties about the relationship of root diameter to their function, generally, the root length within a soil volume unit has been adopted (root length density, L_v) to characterize root presence (Klepper, 1992). In the trench or profile wall method (Bohm, 1979), digital image analysis can provide information for the required quantitative root analysis. From the digital pictures of roots exposed in a trench wall, root area (A_p) and root length (L_p) can be estimated using an image processing technique (Crestana et al., 1994). Moreover, root biomass can be determined from root area measurements, as suggested by Ruark & Bockhein (1988) in aspen roots analysis in trench walls. Many other studies have shown the feasibility, accuracy and procedures of digital image analysis to estimate root area, root length and root diameter (Bauhus & Messier, 1999; Commins et al., 1991; Dowdy et al., 1998; Kaspar & Ewing, 1997; Kimura et al., 1999; Murphy & Smucker, 1995; Tagliavini et al., 1993).

The objectives of this study were to analyze root distribution of grapevines, and to determine root distribution as affected by irrigation methods and soil types. Specifically, differences in root characteristics were measured for microsprinkler and drip irrigation systems for the IAC-313 rootstock in Petrolina, PE, Brazil. For this purpose, both the soil profile method with digital image analysis (Crestana et al., 1994; Bassoi et al., 1999) and the monolith method (Bohm, 1979) were used. In another commercial grape growing area located in Juazeiro, BA, Brazil, an evaluation of root distribution of the same rootstock in a different soil type was also conducted, using the trench method only. Both neighboring counties are sited along the São Francisco River and are important table grape production areas of the São Fancisco Valley of the semi-arid region of northeastern Brazil.

MATERIAL AND METHODS

Petrolina County

Two field trials were carried out in Petrolina, PE, Brazil (09° 09' S, 40° 22' W, altitude 365.5 m). The region has characteristics to grow grapevine with two harvests a year, because of the warm temperatures that prevail throughout the year (Araújo, 1994). The grapevines cv. Italia grafted on the rootstock IAC-313 were planted in September 1991 in a 4 x 2 m grid (rows x plants) on a Typic Acrustox of average bulk density 1.6 Mg m^{-3}. The soil is classified as medium-textured (140 g kg^{-1}, 80 g kg^{-1} and 780 g kg^{-1} of clay, silt and sand, respectively), and the average soil water retention corresponds to 128.4 g kg^{-1} and 44.9 g kg^{-1} at 10 kPa and 1500 kPa, respectively. The chemical characteristics of the soil profile (Table 1) were determined down to the 1 m depth as described by EMBRAPA (1997). Grapevines were irrigated either by microsprinkler (flow rate of 40 L h^{-1} with a wetting radius of 2 m), spaced every 4 m along the plant row and centered between two plants, or by drip emitters (flow rate of 3.7 L h^{-1}), spaced 1 m apart along a double drip line (10 cm distance between plant row and drip lines on either side of the grapevines). Irrigation scheduling was based on pan-A evaporation data, using crop coefficients obtained in 1994 in the same area (Teixeira et al, 1999), and identical daily water application amounts were used for both irrigation systems. Root distribution was measured after blooming in two subsequent growing seasons, using the soil profile method combined with digital image analysis (Crestana et al., 1994; Bassoi et al., 1999) and the monolith method (Bohm, 1979).

Soil profile method

For crops on both irrigation systems, 1-m deep and 2-m wide trenches were dug between plant rows to expose half of the root system of each of the two grapevine plants, in October 1995 and for other two in April 1996 (2 m long wall, one plant along each side of the trench). The distance between trench wall and center of plant row was 1 m.

A thin layer of soil (1-2 cm) was carefully removed from the excavated vertical soil wall along the whole trench, and visible roots (generally with diameter larger than 1 mm) were painted with white ink to enhance color contrast of the roots and the soil. A 1 × 1 m wire-wood frame with a wire grid of 0.2 × 0.2 m was pressed against the trench wall and video images were collected for each of the 0.04 m^2 areas along the whole trench. The image collection procedure was repeated in several distances (1.0, 0.8, 0.6, 0.4, and 0.2 m) from plant row. Root images were digitized with a resolution of 640 x 480 pixels, saved as BMP files and processed by the Integrated System for Root and Soil Coverage Analysis (SIARCS®) software (Crestana et al., 1994). From each image, root areas (A_p, m^2) were determined. Average A_p values ($\overline{A_p}$) were computed from two subsequent trench walls, *e.g.*, making up the front and back of each 0.2 m thick soil slab, corresponding to distances of 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 m from the plant row.

Table 1 - Chemical characteristics of the soil of Petrolina and Juazeiro trials.

depth	pH	E.C.	P	O.M.	Ca^{2+}	Mg^{2+}	Na^+	K^+	H + Al	Al^{+3}	V
m		dS m^{-1}	mg dm^{-3}	g dm^{-3}	mmol$_c$ dm^{-3}						%
					Petrolina microsprinkler 1995						
0-0.2	6.2	0.33	107	0.96	2.5	2.0	0.02	0.6	3.0	0.5	63
0.2-0.4	6.2	0.49	96	0.61	2.6	1.4	0.02	0.6	2.4	0.5	66
0.4-0.6	5.1	0.84	93	0.53	2.4	1.5	0.03	0.5	3.8	2.0	54
0.6-0.8	4.4	0.73	-	-	1.4	1.6	0.03	0.5	4.7	8.5	43
0.8-1.0	4.2	0.57	-	-	1.6	1.7	0.03	0.4	5.1	10.5	42
					Petrolina drip 1995						
0-0.2	6.5	1.21	117	0.73	2.3	1.7	0.03	0.6	1.8	0.5	72
0.2-0.4	6.0	0.87	123	0.55	2.9	1.0	0.03	0.6	1.6	0.5	74
0.4-0.6	5.4	1.18	94	0.47	2.6	2.1	0.05	0.6	2.6	1.0	67
0.6-0.8	4.6	1.19	-	-	3.4	1.0	0.05	0.6	2.4	2.5	68
0.8-1.0	4.4	1.49	-	-	2.7	2.1	0.05	0.5	2.9	3.5	65
					Petrolina microsprinkler 1996						
0.0-0.2	4.5	0.87	37	1.26	0.9	0.6	0.02	0.2	4.1	3.0	31
0.2-0.4	4.7	0.75	69	1.54	1.7	0.5	0.02	0.3	4.6	4.0	34
0.4-0.6	5.3	0.74	59	1.05	2.0	1.2	0.02	0.4	3.5	1.5	50
0.6-0.8	5.0	0.91	83	0.94	2.6	1.0	0.03	0.5	2.9	1.5	58
0.8-1.0	5.4	1.57	69	0.63	3.0	1.8	0.11	0.7	1.6	1.0	78
					Petrolina drip 1996						
0.0-0.2	5.0	0.63	78	1.39	2.0	0.9	0.05	0.3	3.3	1.5	50
0.2-0.4	4.9	0.56	96	1.09	1.7	0.5	0.02	0.3	3.9	2.0	39
0.4-0.6	4.5	0.69	127	0.88	1.8	1.2	0.03	0.3	4.9	4.0	41
0.6-0.8	5.2	0.90	79	0.91	2.6	1.3	0.05	0.4	0.5	1.0	89
0.8-1.0	5.6	1.30	32	1.06	3.4	1.2	0.09	0.6	1.5	0.5	78
					Juazeiro furrow 1997						
0.0-0.2	7.0	0.66	120	1.96	7.6	0.7	0.07	0.6	0.0	0.0	100
0.2-0.4	6.7	0.72	64	0.98	6.9	2.2	0.04	0.6	1.4	0.1	87
0.4-0.6	6.6	0.39	16	0.71	6.9	1.2	0.05	0.5	1.5	0.1	85
0.6-0.8	6.6	0.28	-	-	8.1	2.5	0.05	0.3	1.6	0.1	87
0.8-1.0	6.5	0.31	-	-	8.2	2.1	0.07	0.3	1.2	0.1	90

E.C.: electric conductivity; O.M.: organic matter

Monolith method

After image collection of each trench wall, monoliths of 0.008 m^3, corresponding to the 0.2×0.2 m imaged area and to the 0.2 m soil thickness, were sampled for two plants, in 1995 and 1996. As the trenches were excavated between two plant rows, sampling was performed on root systems on each side of the trenches. Monoliths were collected at distances of 1.0-0.8, 0.8-0.6, 0.6-0.4, and 0.4-0.2 m from plant rows. In the field, the roots of the monoliths were carefully separated from the soil using a 4 mm mesh sieve. Subsequently, fresh roots were washed in the laboratory, classified in four diameter (d) intervals: $d \leq 2$ mm, $2 < d \leq 5$ mm, $5 < d \leq 10$ mm, and $d > 10$ mm, and oven dried at 65°C before counting. For each diameter interval, dry weight (D_w, g) and root length (L, m) was estimated using the line intersection method (Tennant, 1975). Grid sizes of 0.01 x 0.01 m and 0.02 x 0.02 m were used for counting root line intersections for $d \leq 10$ mm and $d > 10$ mm, respectively. Root length density (L_v, m m^{-3}) was obtained from the estimated L divided by the monolith volume (V = 0.008 m^3).

Statistical analysis

The root parameters (D_w, $\overline{A}_p$ and L_v) for the two irrigations systems were analyzed in relation to four distance intervals from plants, and five soil depths using a repeated measure design. As measurements were repeated over the soil profile, the root count at one depth (soil layer 0.2 m thick) is not independent of the root count of the next depth, for a homogeneous soil. So counts over several depths were considered repeated spatial measurements (Morano & Kliewer, 1994). For each irrigation system, two replications were sampled and analyzed for D_w, $\overline{A}_p$ and L_v data of 1995 and 1996.

To better understand the relationships between root measurements, $\overline{A}_p$ - was calculated from the front and the back sides of a monolith - was correlated with D_w and L_v, obtained from the inside of the same soil volume. Values of D_w, L_v, and $\overline{A}_p$ were added over each 0.2 m soil depth and along the trench wall, and fractional distributions of root parameters were also correlated. These comparisons were performed for all distance intervals and for both irrigation systems.

Model application

A simple model to predict the vertical root distribution was applied to root parameters measured by both, the trench wall and monolith methods, based on an asymptotic equation (Gale & Grigal, 1987): $Y = 1 - (B^D)$, where Y is the cumulative fraction of a root density parameter (between 0 and 1) measured from soil surface to a depth D (m), and B is a fitting coefficient.

Juazeiro County

In a separated field experiment in 1997, the root distribution of the grapevine cv. Piratininga, grafted on the rootstock IAC-313, was measured using the soil profile method combined with digital image analysis, to demonstrate its application in a farmer's field. Grapevines were planted in 1990 using a 3.5 x 2 m spacing, in a clayey soil (540 g kg^{-1}, 90 g kg^{-1}, 370 g kg^{-1} of clay, silt and sand, respectively), and with a bulk density of 1.4 Mg m^{-3}). Average soil water retention at 10 kPa and 1500 kPa were 19.6 g kg^{-1} and 10.3 kg^{-1}, respectively. Chemical characteristics of this soil (Table 1) were also determined as described by EMBRAPA (1997). Vines were irrigated using furrows on each side of the vine row. Two trenches (1 m deep and 2 m long) were excavated to expose the rooting system of one vine trunk in the center of each trench. Field procedures for image collection were the same as described earlier. Root distribution was analyzed at several distances (1.0, 0.8, 0.6, 0.4, and 0.2 m) from the trunk. In addition the A_p, root length in the soil profile (L_p, m) was measured in this trial. Average values ($\overline{A}_p$ and $\overline{L}_p$, respectively) were obtained from two subsequent trench walls as described in the Petrolina County experiment. In addition, root length density data were computed from the images, assuming that the volumetric root fraction (VRF, m^3 of roots per m^3 of soil) is equal to the areal root fraction (ARF, m^2 of roots per m^2 of soil), and that the total root volume within each 0.2 x 0.2 x 0.2 m^3 bulk soil volume is equal to $\pi \hat{r}^2\ \text{Ł}_p$ (Bassoi et al., 1999):

$$VRF = ARF \Rightarrow (\pi \hat{r}^2\ \text{Ł}_p) / (0.2 \times 0.2 \times 0.2) = \overline{A}_p / (0.2 \times 0.2)$$

$$\overline{L}_p = (\overline{A}_p \times 0.2) / (\pi \hat{r}^2)$$

$$L_{v,p} = \text{Ł}_p / (0.2 \times 0.2 \times 0.2) = ARF / (\pi \hat{r}^2)$$

where $L_{v,p}$ denotes the root length density as estimated from the soil profile method (m m^{-3}), and $\hat{r}$ (m) is the average root radius as estimated by the (A_p / L_p) ratio of both images of the 0.008 m^3 root volume (both trench faces).

RESULTS AND DISCUSSION

Petrolina County

A considerable variation on the total value (whole plant) of D_w and L was observed between the two grapevines in both years, even on a same irrigation system. In 1995, total D_w values were 1.23 and 0.34 kg for microsprinkler, and 1.03 and 0.71 kg for drip irrigated plants. Corresponding total L values were 473.5 and 252.5 m for microsprinkler, and 475.8 and 417.2 m for drip irrigated plants. In 1996, total D_w from vines irrigated by microsprinkler were 1.36 and 0.46 kg, while for those irrigated by drip values were 0.84 and 1.06 kg. Respectively, total L values were 564.5 and 264.2 m for microsprinkler, and 396.8 and 506.0 m for drip irrigated plants. In both years, roots with $d \leq 5$ mm were approximately 50 % or more of total D_w, while roots with d ≤ 2 mm corresponded to at least 80 % of total L. Other studies have shown that most of the roots were found within d < 0.5 mm (van Zyl, 1988), d < 1 mm (Morlat & Jacquet, 1993), and d < 2 mm (Morano & Kliewer, 1994; Padjett-Johnson, 1999). The variation is possibly a consequence of the extension and direction of root growth, which is predominantly a random phenomenon influenced by gravity, soil resistance, temperature and availability of carbohydrate from the leaves, nutrient and water availability and gaseous exchange within the soil (Rowe, 1993). Also, strong spatial heterogeneity of root distribution, volumetric root expansion, frequent asymmetry on either side of plant rows, and a great variability in root diameter are the main constraints for root studies in vineyards (Morlat & Jacquet, 1993). The average L for drip (448.93 ± 50.64 m) was higher than that of microsprinkler-irrigated plants (388.70 ± 155.05 m), which is similar in relation to other results (Stevens & Douglas, 1994). Variability of total root length of vines did not make possible any conclusion on the effect of soil texture on root development (Nagarajah, 1987).

There were no differences between root parameters under both irrigation systems while all comparisons were significant between soil profiles, soil depths and their interactions. The closer to the trunk, the greater is the amount of roots in the horizontal direction, as well as in the vertical direction. D_w was not significant for irrigation and soil profile interaction in 1995, and for irrigation and soil depth interaction in 1996, while L_v and $\overline{A}_p$ presented significant differences for both years (Table 2).

In the horizontal direction (irrigation and soil profile interaction), the t-test was significant for root parameters in some sites. For the most distant samples from trunk (0.8-1 m), D_w and $\overline{A}_p$ of the microsprinkler-irrigated grapevines presented higher values (except for $\overline{A}_p$ in 1995), while near the trunk (0.2-0.4 and 0.4-0.6 m), drip-irrigated plants presented significant higher root parameters. In the vertical direction (irrigation and soil depth interaction), soil layers until 0.6 m presented some root parameters with higher values for plants irrigated by drip, and some higher values for plants irrigated by microsprinkler for the deeper soil layer (Table 3).

In the significant interactions between irrigation and soil profile and soil depth, the t-test between the same soil depth interval in the same soil profile indicated that few portions of the root system had differences between both irrigation systems. But for those with differences, this occurred at the greatest distance from the trunk (0.8-1 m soil profile) and in the deepest soil layer (0.8-1 m depth); microsprinkler-irrigated plants presented greater root presence than those irrigated by drippers, in almost all sampling sites. A clear tendency of greater values of drip irrigated plants appeared in the upper 0.6 m soil depth and in the soil profiles between 0.2 and 0.6 m**.** L_v and $\overline{A}_p$ values of 1996 trial are presented over the entire trench walls in vertical and horizontal directions in Figures 1 to 4. Closer to the trunk, values increased as well as the ones under microsprinkler presented higher values than those under drip irrigation in 0.8-1 and 0.6-0.8 m soil profiles, while the opposite occurred for 0.4-0.6 and 0.2-0.4 m soil profiles. Higher values of L_v and $\overline{A}_p$ were found near the soil surface due to manure application, a common practice of the grapevine production system in the São Francisco Valley. Generally, table grape growers have been applying 0.02-0.04 m^3 of manure per vine in every growing season.

As grapevine root distribution in the soil profile is dependent of edaphic conditions (Nagarajah, 1987; Morlat & Jacquet, 1993). Soil depth of highest root presence varied around 0.4 m (Nappi et al., 1985), 0.5 m (Padgett-Johnson, 1999), 0.8 m (Stevens & Douglas, 1994), 1.0 m (Araújo et al., 1995), and 2.4 m (Williams & Smith, 1991). Some of the influence factors are the irrigation system, age of the plant, rootstock, spacing grid, and physic-chemical soil conditions. In this study, the upper 0.4 m soil profile presented the highest amount of root in both soils. Supposedly application of mamure has provided better root proliferation conditions in this soil

Table 2 - Analysis of variance ($P < 0.05$) with a repeated measurement design of root dry weight (D_w, kg), root length density (L_v, m m^{-3}), and root area ($\overline{A}_p$, m^2) of the grapevine cv. Italia grafted on rootstock IAC-313, for different irrigation systems, soil profiles and depths in Petrolina.

root parameter and year	irrigation system	soil profile	soil depth	irrigation and soil profile	irrigation and soil depth	soil profile and depth	irrigation soil rofile and depth
D_w 1995	ns	10^{-6}	10^{-6}	ns	0.002589	10^{-6}	0.005380
D_w 1996	ns	10^{-6}	10^{-6}	0.024387	ns	10^{-6}	0.017656
L_v 1995	ns	10^{-6}	10^{-6}	0.005955	10^{-6}	10^{-6}	10^{-6}
L_v 1996	ns	10^{-6}	10^{-6}	0.005114	0.000791	10^{-6}	10^{-6}
$\overline{A}_p$ 1995	ns	10^{-6}	10^{-6}	0.039798	2.10^{-6}	10^{-6}	0.002896
$\overline{A}_p$ 1996	ns	10^{-6}	10^{-6}	0.005879	0.019473	10^{-6}	10^{-6}

ns - not significant

Table 3 - Comparison performed by the t-test ($P < 0.05$) between drip and microsprinkler irrigation systems of root dry weight (D_w, kg), root length density (L_v, m m^{-3}), root area ($\overline{A}_p$, 10^{-4} m^2) of the grapevine rootstock IAC-313 from significant interactions between irrigation versus soil profile and irrigation versus soil depth, for Petrolina.

root parameter and year	soil profile - m							
	0.2-0.4		0.4-0.6		0.6-0.8		0.8-1	
	micro	drip	micro	drip	micro	drip	micro	drip
D_w 1996	7.28 b	10.36 a	4.16 a	4.51 a	3.03 a	2.35 a	3.34 a	1.93 b
L_v 1995	319.7 a	337.9 a	244.0 b	389.2 a	192.6 a	226.8 a	151.2 a	160.4 a
L_v 1996	408.9 a	353.4 a	246.0 b	349.4 a	201.4 a	194.5 a	217.4 a	171.6 a
$\overline{A}_p$ 1995	2.68 b	3.39 a	3.94 b	5.37 a	5.98 b	9.76 a	9.70 b	12.88 a
$\overline{A}_p$ 1996	11.80 b	14.25 a	8.74 b	11.26 a	6.34 a	6.30 a	4.87 a	3.85 b

root parameter and year	soil depth - m									
	0-0.2		0.2-0.4		0.4-0.6		0.6-0.8		0.8-1	
	micro	drip	micro	drip	micro	drip	micro	drip	micro	drip
D_w 1995	6.45 a	8.69 a	3.69 b	6.53 a	3.96 a	2.16 a	2.65 a	2.17 a	2.83 a	2.10 a
L_v 1995	410.6 b	566.0 a	211.9 b	313.8 a	141.6 a	169.3 a	156.7 a	178.3 a	213.7 a	167.8 a
L_v 1996	563.6 a	524.9 a	243.8 b	384.2 a	118.2 b	172.4 a	142.9 a	176.1 a	204.2 a	147.8 b
$\overline{A}_p$ 1995	10.58 b	18.34 a	7.69 a	8.98 a	2.07 b	3.75 a	3.76 a	4.55 a	3.78 a	3.62 a
$\overline{A}_p$ 1996	18.34 a	18.24 a	9.45 b	13.89 a	3.71 b	5.76 a	4.47 a	4.37 a	3.98 a	2.31 b

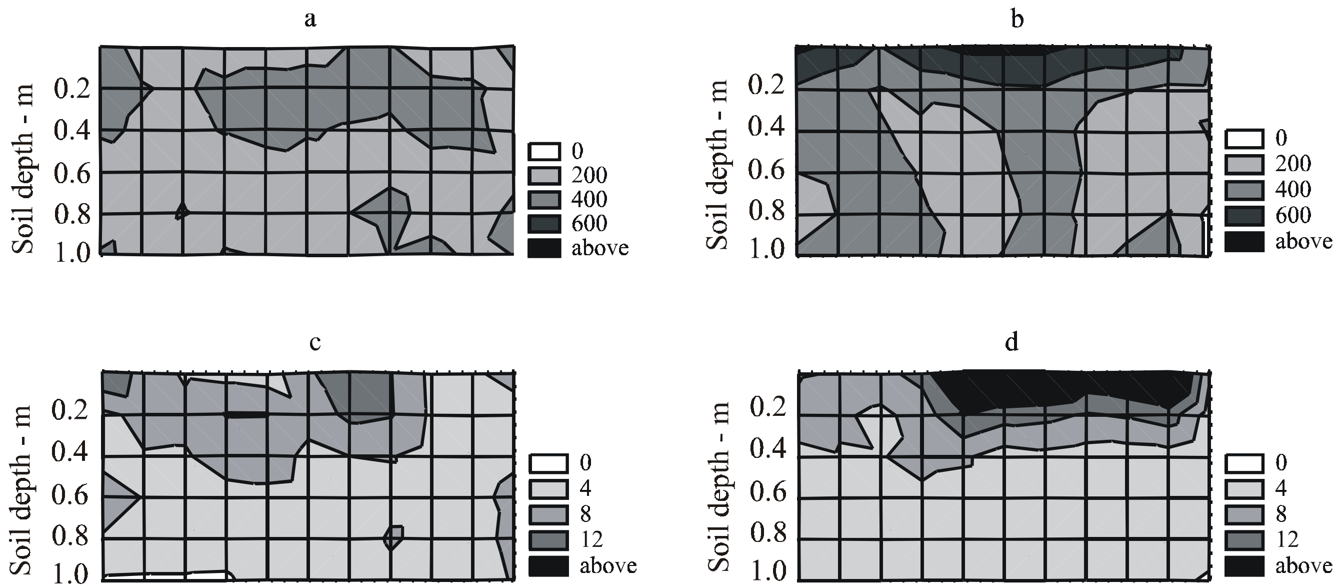

Figure 1 - L_v - root length density - (a,b – m m^{-3}) and $\overline{A}_p$ – root area (c,d – 10^{-4}m^2) distributions in the 0.8-1 m soil profile under drip (a,c) and microsprinkler (b,d) irrigation systems in Petrolina.

layer. Higher grapevine root presence in a sandy soil horizon was observed and related to higher organic matter content (Morlat & Jacquet, 1993). The main factors for shallow rooting in tropical soils are low pH, high exchangeable aluminum, compaction, inadequate aeration, and low retention and movement of water (Reichardt, 1981). In this study, soil pH ranged from 4.4 (deeper to upper layers) to 6.0 (upper layers), and organic matter content in deeper layers was low. Also, this soil presented over the 1 m depth low level of sodium, medium levels of calcium and magnesium, high contents of potassium and phosphorus, and medium base saturation (Table 1).

Stevens & Douglas (1994) found that in the horizontal direction, roots of drip-irrigated plants were concentrated under the vine row, and 50% of the root length was within the 45 cm distance from the plant row in comparison with 35% of the plants irrigated by microsprinkler. A decrease in the grapevine root length from 0.3 m to 0.9 m distance from the trunk was also observed by Nagarajah (1987). In this study area, a greater amount of roots was within the 0.6 m distance from the plant row.

Water application by drippers close to the trunk provides smaller wetted soil volume mainly in the closer

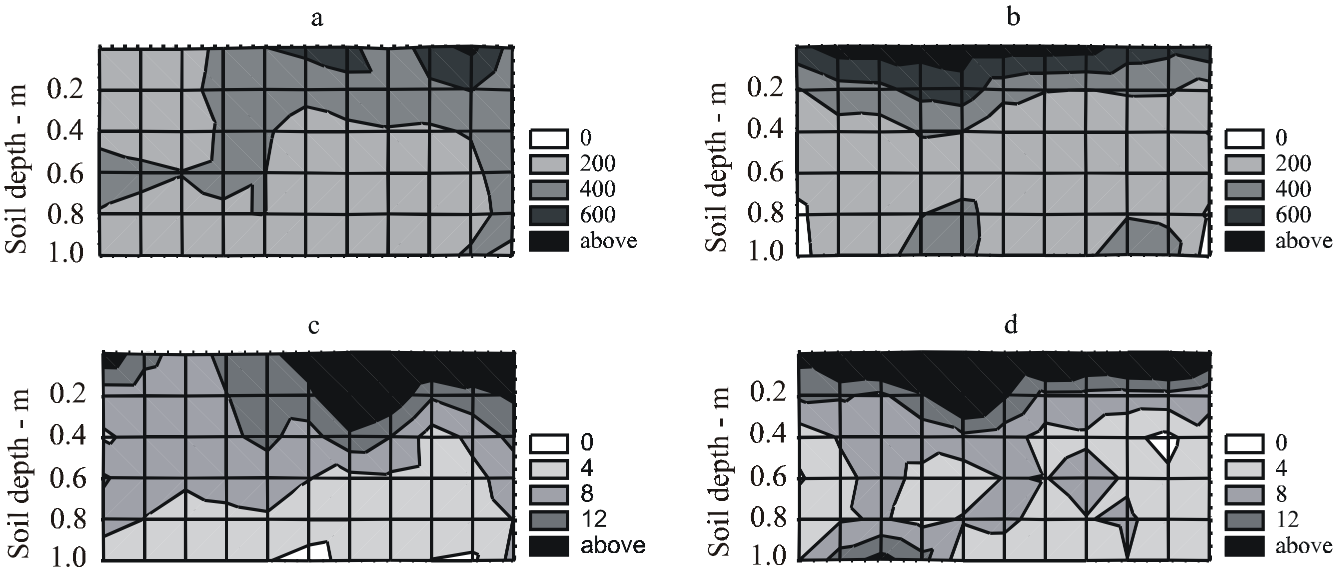

Figure 2 - L_v - root length density (a,b – m m^{-3}) and $\overline{A}_p$ – root area (c,d – $10^{-4}m^2$) distributions in the 0.6-0.8 m soil profile under drip (a,c) and microsprinkler (b,d) irrigation systems in Petrolina.

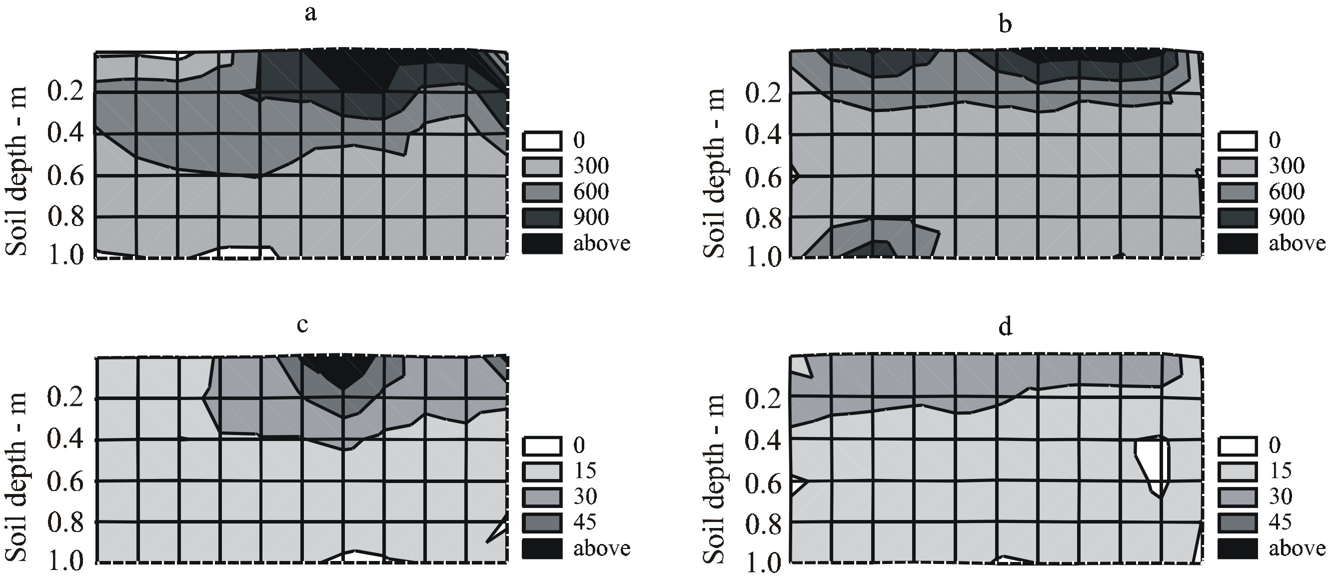

Figure 3 - L_v - root length density (a,b – m m^{-3}) and $\overline{A}_p$ – root area (c,d – $10^{-4}m^2$) distributions in the 0.4-0.6 m soil profile under drip (a,c) and microsprinkler (b,d) irrigation systems in Petrolina.

soil portions at vertical and horizontal directions to trunk. Therefore, in some portions of the soil near the trunk, L_v and $\overline{A}_p$ were higher for drip than for the correspondent positions in plants irrigated by microsprinklers. But root growing was spread over the longitudinal direction in relation to the plant rows, because of the 2 m wetting radius of the microsprinklers, emitter disposals on each 1 m along the drip line, and the manure application, close and along plant rows. Besides of the differences on methods used for root sampling and measurement, L_v values are in accordance with other authors (Nagarajah, 1987; van Zyl, 1988).

Normal precipitation (1963-1996) at Petrolina, measured at the climatic station located within the experimental area, was 573 mm per year, and 512 mm occur between November and April (rainy season). As grapevine is cultivated over the entire year in this tropical fruit growing area, with two harvests per year (Araujo, 1994), the root growth during the rainy season may contribute also to minimize differences in root development under microsprinkler and drip irrigation systems.

Correlations obtained between D_w, L_v and $\overline{A}_p$ for 1996 data were slightly better than those for 1995, but in both years the r^2-values were not sufficiently high, even those between parameters measured inside the monolith. This occurred because the trench wall exposes part of the root system present inside the soil volume, and because roots with same D_w may have different L values or vice-versa because of different root diameter. Correlation performed between the averaged fractional distribution of the root parameters for each 0.2 m soil layer along the trench wall, considering each plant and each soil profile, were high. The integration of the root parameter values provided this better relationship (Table 4). It means a good correspondence and, therefore, a support to the feasibility of the digital image analysis for this purpose.

The model to predict vertical root distribution was tested with D_w, L_v, and $\overline{A}_p$ measured in 1996 in two vines irrigated by microsprinkler for all soil profiles together (Figure 5). The variability of the values for a same soil depth is attributed to the variation of root presence in the different distances from the trunk, as already discussed. The equations presented high r^2 values, and the D_w, L_v, and $\overline{A}_p$ variances were explained by 91.3, 89.5, and 95.2 %, respectively. Therefore, the vertical root distribution analysis can be accomplished using the parameters measured by both methods with this simple model, with acceptable accuracy.

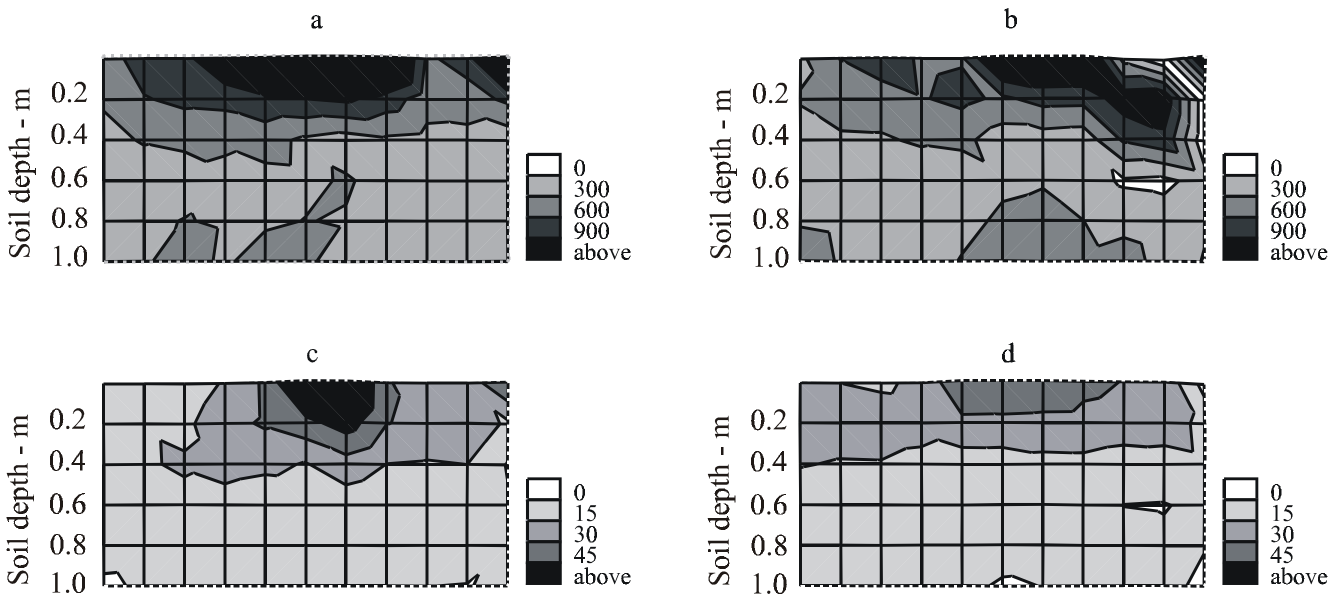

Figure 4 - L_v - root length density (a,b – m m^{-3}) and $\overline{A}_p$ – root area (c,d – 10^{-4}m^2) distributions in the 0.2-0.4 m soil profile under drip (a,c) and microsprinkler (b,d) irrigation systems in Petrolina.

Table 4 - Linear equations (y = a + bx), correlation coefficients for root dry weight (D_w, kg), root length density (L_v, m m^{-3}), root area ($\overline{A}_p$, m^2), and root length ($\overline{L}_p$, m) of the grapevine rootstock IAC-313, and their fractional distribution comparisons in Petrolina (1995 and 1996) and Juazeiro (1997).

year	coordinates x y	irrigation system	parameter a	b	r^2	fractional distribution a	b	r^2
1995	D_w x L_v	micro	164.898	15.845	0.562	3.294	0.835	0.855
		drip	183.965	21.966	0.614	3.275	0.836	0.916
	D_w x $\overline{A}_p$	micro	3.503E-4	3.317E-5	0.417	5.045	0.748	0.698
		drip	2.257E-4	4.691E-5	0.646	2.777	0.861	0.869
	L_v x $\overline{A}_p$	micro	9.624E-5	1.692E-6	0.599	3.683	0.816	0.744
		drip	1.084E-4	1.148E-6	0.566	1.053	0.947	0.873
1996	D_w x L_v	micro	173.815	19.365	0.592	4.188	0.791	0.869
		drip	170.316	23.150	0.724	5.316	0.734	0.866
	D_w x $\overline{A}_p$	micro	5.256E-4	6.426E-5	0.602	3.423	0.829	0.913
		drip	5.350E-4	7.447E-5	0.663	6.362	0.682	0.741
	Lv x $\overline{A}_p$	micro	2.233E-4	2.240E-6	0.687	1.110	0.944	0.946
		drip	1.180E-4	2.751E-6	0.783	0.628	0.969	0.893
1997	$\overline{A}_p$ x $\overline{L}_p$	furrow	0.897	2292.72	0.858	4.350	0.783	0.968
	$\overline{A}_p$ x $L_{v,p}$	furrow	39.749	47193.44	0.535	9.407	0.530	0.745
	$\overline{L}_p$ x $L_{v,p}$	furrow	24.778	19.316	0.585	6.438	0.678	0.771

Juazeiro County

Root distribution of the grapevine cv. Piratininga grafted on rootstock IAC-313 was evaluated by digital image analysis to obtain $\overline{A}_p$, $\overline{L}_p$, and $L_{v,p}$, and an example of these results is presented for $\overline{A}_p$ in Figure 6 for comparison with results from the experimental area (Petrolina County). Roots reached the 1 m depth and the 1 m distance from the trunk and the amount increased in relation to the decrease of the distance from the plant row. This soil presented a higher pH and nutrient content than that of Petrolina (Table 1). The lack of roots near soil surface, specially in 0.4-0.6, 0.6-0.8, and 0.8-1 m distances, can be attributed to no manure application in this area. A much less fine root proliferation was observed in the field, particularly in the 0-0.4 m depth, as compared to the Petrolina County trial.

As observed for the experimental area, higher correlation coefficients were obtained with the fractional distribution correlation than with the parameter comparisons (Table 4). L_v calculated by monolith data in the experimental area ranged from 10 to 2730 m m^{-3}, while $L_{v,p}$ (using trench wall data) of the Juazeiro County trial varied from 1 to 930 m m^{-3}. The differences in magnitude between both root parameters are a consequence of the whole and partial exposure of the roots for measurement (respectively, L in the monolith method, and A_p and L_p in the soil profile method). In an indirect way, we found that fractional L_p and $L_{v,p}$ may be used to evaluate root distribution, given their correlation with $\overline{A}_p$.

The range of root diameter over the trench wall and estimated by A_p/L_p ratio was 2.1 - 3.4, 2.1 - 3.3, 2.2 - 3.7, 1.9 - 2.7, 0.9 - 2.9 mm, for soil profiles at 0.2, 0.4,

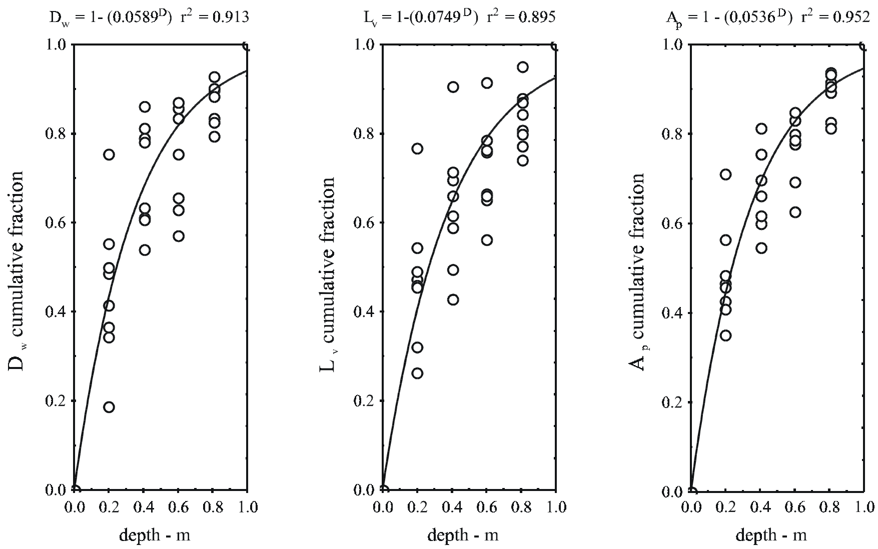

Figure 5 - Vertical root distribution based on the model Y = 1-(B^D) of D_w (root dry weight), L_v (root length) and $\overline{A}_p$ (root area) measured in all soil profiles of two vines irrigated by microsprinklers in Petrolina (1996).

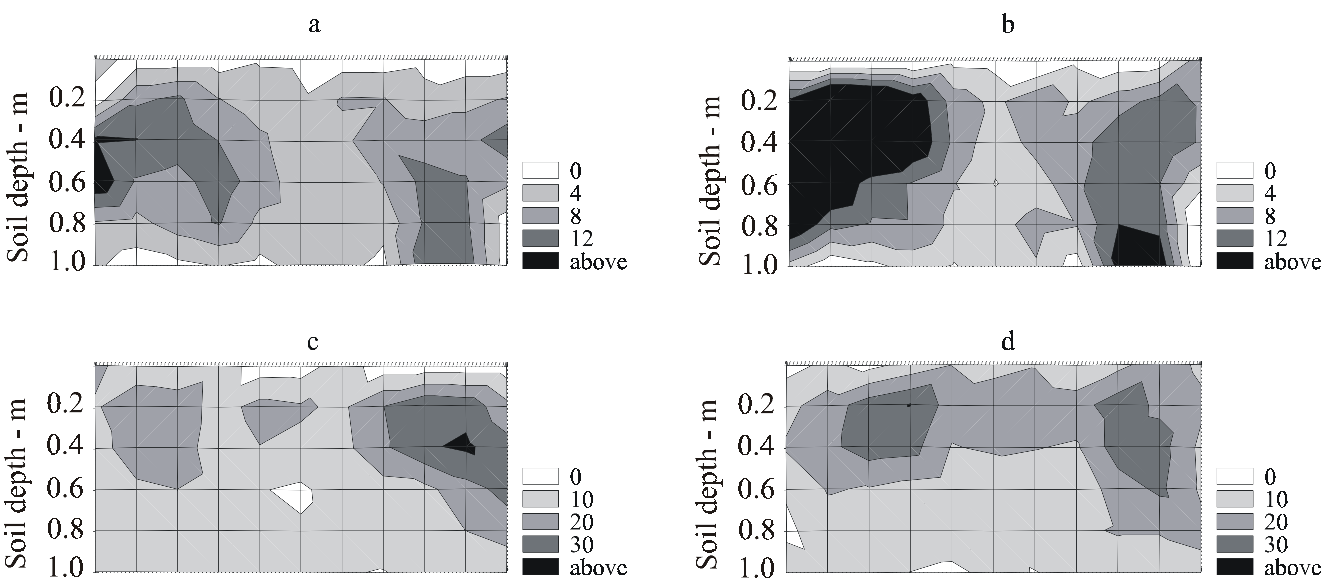

Figure 6 - $\overline{A}_p$ - root area (10^{-4} m^2) distribution over 0.8-1 (a), 0.6-0.8 (b), 0.4-0.6 (c), and 0.2-0.4 m (d) soil profiles in Juazeiro.

0.6, 0.8, and 1 m from plant rows. These estimations are within the diameter intervals where most of D_w and L were found in the Petrolina County and by other studies already mentioned.

In conclusion, the grapevine cv. Italia, grafted on the rootstock IAC-313 and grown under drip and microsprinkler irrigation, presented a root system that reached 1 m in the vertical and horizontal directions from the trunk, in a coarse textured soil. However, much of the root system was present in the soil volume covered by the 0.4 m depth and by the perpendicular distance of 0.6 m from plant row. In some portions of the soil, root amounts were higher as the distance from the trunk increased (vertical and horizontal directions) for plants under microsprinkler irrigation, while drip irrigated grapevines presented higher root presence near to the trunk. Roots with diameter less than 2 mm were at least 80% of the total root length.

Correlation among dry weight, root length density and root area were reasonable, but correlation among their fractional distributions over the soil profile were higher, which lead to similar conclusions on root distribution. Because of its good correlation with root length density, root area or root length estimated by the soil profile method combined with digital image analysis can be used to evaluate grapevine rootstocks.

ACKNOWLEDGEMENT

To CNPq for finantial support (project n° 521376/95-5).

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Received March 20, 2002