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# Root Distribution of Peach Rootstocks Affected by Soil Compaction and Acidity

**Henrique Belmonte Petry[(1)], Michael Mazurana[(2)*], Gilmar Arduíno Bettio Marodin[(3)], Renato Levien[(2)], Ibanor Anghinoni[(2)], Clésio Gianello[(2)] and Sergio Francisco Schwarz[(3)]**

[(1)] Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Estação Experimental de Urussanga, Urussanga, Santa Catarina, Brasil.
[(2)] Universidade Federal do Rio Grande do Sul, Departamento de Solos, Porto Alegre, Rio Grande do Sul, Brasil.
[(3)] Universidade Federal do Rio Grande do Sul, Departamento de Fitotecnia, Porto Alegre, Rio Grande do Sul, Brasil.

**ABSTRACT:** Root growth can be limited by physical and chemical conditions of the soil. Compacted and acidic soils, where there is an occurrence of exchangeable Al, constitute barriers to use of the soil by plant roots. The hypothesis of this study was that physical and chemical properties of the inter-row soil of a peach orchard influence the root distribution of different rootstocks. The aim of this study was to describe and register the soil physical and chemical properties and root distribution in the soil profile of the inter-row of seven years old mature peach (*Prunus persica*) orchard. Samples of soil (classified as an *Argissolo Vermelho Distrófico típico* [Rhodic Paleudult] with 180 g $kg^{-1}$ clay, 120 g $kg^{-1}$ silt, and 700 g $kg^{-1}$ sand) and roots were collected from orchard inter-rows of 'Maciel' peach, grafted onto 'Okinawa' and 'Nemaguard' rootstock, at 1.5, 2.0, and 2.5 m from the trunk, and at every 0.10 m, up to a depth of 0.50 m. The soil samples were sieved and the roots washed. A subsample was removed from each sample for chemical analysis. Resistance to penetration (RP) was used as an indicator of soil compaction. A close relationship was found among chemical properties, RP, and root distribution. Root density was affected by the presence of compacted regions (RP >2,000 kPa) and by high Al saturation in the exchange complex in the soil profile. There was a reduction in the frequency of thick roots (Ø >2 mm) in the samples collected in portions of compacted soil and at increasing soil depth. The compacted portion of the inter-row limits lateral distribution of the peach tree root system, while aluminum limits its depth.

**Keywords:** *Prunus persica*, resistance to penetration, exchangeable aluminum, root density.

*** Corresponding author:**
E-mail: michael.mazurana@gmail.com

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## INTRODUCTION

Soil is the most complex of all environments, containing solid, liquid, and gaseous phases interrelated in different degrees, depending on prevailing conditions. This complexity poses many challenges to root growth, in both biotic and abiotic terms (Hodge et al., 2009). Physical, chemical, and biological properties in the soil (Bengough et al., 2011) may provide inadequate conditions and limit root growth. Compacted (Jin et al., 2013) and acidic areas, with the occurrence of exchangeable Al (Raij, 2010), constitute barriers to greater use of the soil by plant roots. The ability of soil to supply water and nutrients and its susceptibility to use by the root during expansion are key aspects in growth of the root system (Jin et al., 2013). However, the soil also needs to have sufficient mechanical resistance to promote anchorage of the plants and sustain a pore system which constantly maintains the flow of water and gas necessary for their growth (Gregory, 2006).

The root system of peach [*Prunus persica* (L.) Batsch] trees generally develops up to a depth of 0.50-0.60 m, depending on the type of soil. The roots are white to orange when young, turning dark orange when old, with large lenticels (Bassi and Monet, 2008). The root distribution of a fruit tree depends on numerous factors, related to both the soil and plant, with rootstock being the most important one, in the absence of restrictions from soil factors. Usually, vigorous rootstock has a large quantity of roots. Using a mathematical model, Vercambre et al. (2003) found that in a low density (70 plants $ha^{-1}$) orchard of 'Primerose' peach grafted onto 'Damas' GF 1869' (*P. domestica* × *P. spinosa*) plum tree, without physical and chemical constraints to root development, more than 30 % of the root length is concentrated up to a depth of 0.30 m, and can reach up to 3 m from the stem of the plant, both horizontally and vertically.

The root system is divided into thick and thin diameter roots. Woody roots are thick and lignified by secondary growth and are usually 2 mm or more in diameter, while fibrous roots are thin and flexible and do not have secondary growth (Vercambre et al., 2003). Thick roots are usually woody and play a role in anchoring and conducting water and nutrients to the shoots, while thin roots take up nutrients and water (Forde and Lorenzo, 2001). In view of their functions, thin roots tend to be more affected by chemical and physical disorders.

Soil compaction is a common problem in orchards due to machine traffic, which usually occurs over fifteen times a year to perform management practices common to the technical itinerary of major fruit crops (van Dijck and van Asch, 2002). Associated with this is the fact that most traffic takes place under conditions of soil water content above the plasticity limit, increasing the degree of compaction. The life span of an orchard can extend for over 20 years after the start of production, and during this period there is heavy machinery traffic, always in the same place (Ferree et al., 2004; Minatel et al., 2006; Tolón-Becerra et al., 2010; Medeiros et al., 2013). Mechanical resistance to penetration is a variable commonly used in studies to diagnose the state of soil compaction in orchards, as in van Dijck and van Asch (2002), Tolón-Becerra et al. (2010), Müller et al. (2011), Tolón-Becerra et al. (2012), and Medeiros et al. (2013).

Soil Al toxicity is noteworthy since the root system is most affected, blocking the cell division mechanism and leading to inhibition of root growth. Consequently, roots become atrophied and brittle, root hair development is poor, and root tips are damaged and thickened, ultimately resulting in severe damage to the root system and leading to poor uptake of nutrients and water (Panda et al., 2009). Reduction in root elongation is the first visible symptom of Al stress. However, the presence of other ions reduces the effects of Al in roots, due to interactions and conflicts that occur in the cell membrane. Changes in electrical charges on the root surface by other ions, especially cations, affect sensitivity to Al (Matsumoto, 2002).

The hypothesis of this study was that physical and chemical properties of the soil of the inter-row of a peach orchard influence the root distribution of different rootstocks. The aim of this study was to describe and register soil physical and chemical properties and root distribution in the soil of the inter-row of an orchard of peach grafted onto different rootstocks.

## MATERIALS AND METHODS

We used an experiment already in place at the Agronomic Experimental Station of the Universidade Federal do Rio Grande do Sul (30° 06′ 21″ S, 51° 39′ 57″ W). The soil is classified as an *Argissolo Vermelho Distrófico típico* (Santos et al., 2013), a Rhodic Paleudult, Ultisol (Soil Survey Staff, 2014), with 180 g $kg^{-1}$ clay, 120 g $kg^{-1}$ silt, and 700 g $kg^{-1}$ sand. According to the Köppen classification system, the region has a humid subtropical climate (Cfa) with hot summers. The average annual rainfall is 1,440 mm and the average relative humidity is 77.3 % (Bergamaschi et al., 2012). The experiment was installed in 2006, in a replanting area. The area remained fallow for three years and liming was applied to amend the 0.00-0.20 m soil layer three months before setting up the experiment. Soil analysis and amendment was carried out according to the criteria of the Soil Chemical and Fertility Commission of the states of Rio Grande do Sul and Santa Catarina (CQFSRS/SC, 2004).

The experimental area consisted of an orchard with seven years old of ‘Maciel’ and ‘Chimarrita’ peach trees grafted onto six rootstocks [Peach (*P. persica*): ‘Aldrighi’, ‘Capdeboscq’, and ‘Okinawa’; hybrids (*P. persica* × *P. davidiana*): ‘Flordaguard’ and ‘Nemaguard’; and Japanese apricot (*P. mume*)] in a 2 × 6 factorial arrangement. A randomized block experimental design was used, with three replications consisting of five plants each, with the three central plants constituting the area used for data collection. However, for the sampling of roots and soil characterization in the inter-rows of the orchard, only the combinations of the peach cultivar ‘Maciel’ with the ‘Nemaguard’ and ‘Okinawa’ rootstocks were chosen, due to different vigor induced in the canopy in each canopy:rootstock combination.

The plant canopy was conducted in a “Y” system, with 1.5 m spacing between plants and 5.5 m between rows (1,212 plants $ha^{-1}$). The management practices of the orchard consisted of applications of herbicides, pesticides (fungicides and insecticides), mineral fertilizers, and acidity amendments recommended for the crop, following the standards of Integrated Peach Production (PIP). Around 16 tractor passes each year were performed for pesticide applications (most often from late winter to early summer). Weed control consisted of three to four mechanized mowings per year, concentrated in the spring and summer, with maintenance of vegetation throughout the year, where each operation required passage of the tractor-mower at least twice in each row of the orchard. Fertilizations were performed annually in late autumn and spring (two parcels), according to recommendations of the PIP and CQFSRS/SC (2004) for N, P, and K nutrients. Fertilizer distribution was performed manually under the canopy of the peach trees.

Root and soil samples were collected for chemical analysis, with three replications, from the inter-rows of the orchard at 1.5, 2.0, and 2.5 m from the trunk of the central peach tree of the plot (Figure 1) with the aid of a 500 mm metal tube with inside diameter of 150 mm, made of 4 mm thick steel. This probe was inserted into the soil at collection points with a 10 kg sledge hammer. Afterwards, a hydraulic jack (12 Mg capacity) supported on the front ballast of a tractor with 90 kW and weight of 5.8 Mg was used to drive the probe into the soil profile. The probe was removed from the soil with the help of the tractor hydraulic system, which hoisted the probe with the aid of a chain. Afterwards, these samples were sectioned into 0.10 m layers up to 0.50 m depth from the soil surface with the aid of a large machete, identified, and stored for 10 days in a cold chamber (0 °C).

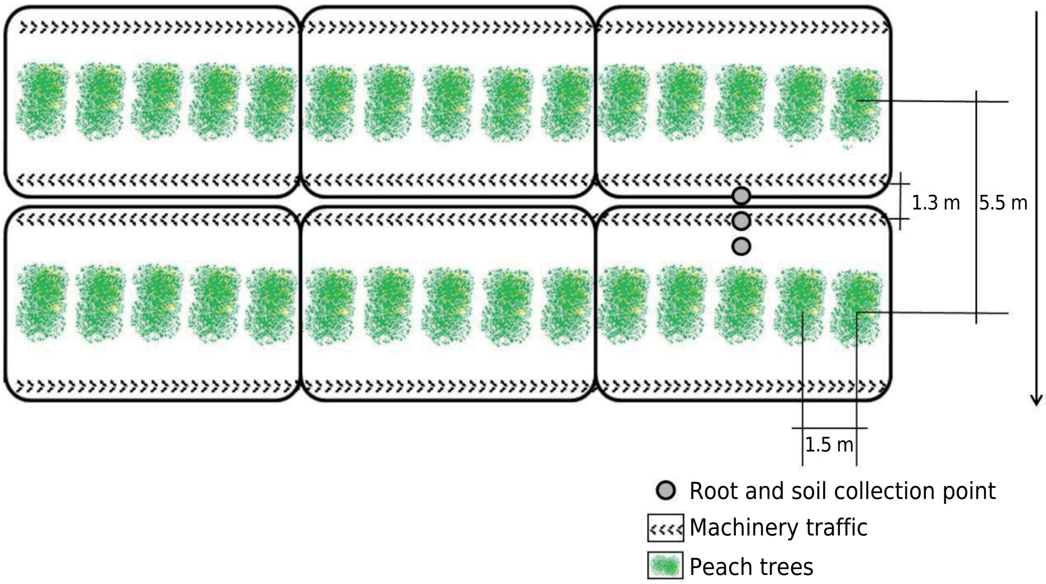


**Figure 1.** Schematic representation of collection points in the inter-row of the experimental plot in the orchard of 'Maciel' peach grafted onto 'Okinawa' and 'Nemaguard'. EEA-UFRGS, Eldorado do Sul, Brazil, 2013. The arrow represents slope direction.

The soil samples were sieved (2 mm) and the roots were thoroughly washed to remove soil trapped around them. A subsample of approximately 0.5 kg of sieved moist soil was withdrawn from each sample for chemical analysis. Interpretation of the levels of each nutrient and soil fertility indicators was performed according to recommendations of the CQFSRS/SC (2004). The washed root samples were then stored in a cold chamber (0 °C) for two days. Afterwards, only the peach tree roots in accordance with the morphological characteristics described by Bassi and Monet (2008) were selected. The roots were fixed in FAA solution (Formaldehyde – 5 %, Glacial acetic acid – 5 %, and ethanol – 90 %) and stored in a refrigerator (7 °C). Quantifications of volume, surface area, and length of the roots, as well as volume distribution into diameter classes, were conducted using the Fiber and Root Analysis System (SAFIRA) computer program (Jorge and Rodrigues, 2008).

Mechanical resistance to penetration (RP), which indicates soil compaction, was measured along the orchard inter-rows using a digital penetrometer (SoloTrack - Falker®) according to the ASAE S313.3 standard (ASAE, 2004). For each canopy/rootstock combination tested, 20 RP readings were performed along the inter-row (spaced every 0.10 m, between 1 and 3 m of the plot plant row) from 0.01 to 0.50 m depth, with three replications. Gravimetric soil moisture was determined in the layer from 0.0 to 0.5 m, every 0.1 m, for each canopy/rootstock combination tested, with three replications.

Variables related to the chemical properties (amount of P and K available, soil pH, and base and aluminum saturation) and physical properties (mechanical resistance, average of each layer in the same portion of the other variables) of the soil and root distribution (root density, specific surface area, and specific length) were related to each other by the Spearman method. The description of resistance to penetration, base and Al saturation, and root density in the soil profile of the inter-rows of the orchard was performed with filled contour charts, adapted from the method used by van Dijck and van Asch (2002) and Black et al. (2010). The frequency of root volume in diameter classes was represented by histograms according to depth for each collection position of the orchard inter-row.

## RESULTS AND DISCUSSION

The soil locations with RP values greater than 2,000 kPa, considered to be compacted (Gregory, 2006), occurred from 1.7 m from the plant row to the center of the inter-row, and were more marked in the 0.05-0.30 m layers, with similar behavior for both rootstocks (Figures 2a and 2b). The compaction occurred across virtually the entire central portion of the orchard inter-rows, due to tractor traffic coupled with different implements (mainly sprayers) that have different distances between axles, and also basically because the traffic does not exactly match the same place since the inter-row spacing is large, in contrast with vineyards. These results are in agreement with van Dijck and van Asch (2002), who assessed the extent of soil compaction of mature orchards and vineyards. Resistance to penetration is influence by both soil density and water content. At the time RP was evaluated, the soil exhibited friable and plastic conditions (water content ranging from 0.12 to 0.17 g $g^{-1}$), according to Beutler (2005). At lower water content conditions (below 0.12 g $g^{-1}$), the RP value increases much more than with high water content (above 0.17 g $g^{-1}$), soil conditions would be restrictive to root growth.

The main reasons for this traffic and consequent compaction are the need for pesticide applications after rainfall to protect crops from pest attacks, especially fungi (Ferree et al., 2004), at which time the ground usually has inappropriate water content for traffic of these machines (in a plastic state), meaning low load-bearing capacity, and repetition of these operations under these conditions several times a year for several years (Ferree et al., 2004; Minatel et al., 2006; Tolón-Becerra et al., 2010; Medeiros et al., 2013). Additionally, the use of a tractor-sprayer with inappropriate wheel sets (bias-ply tires with a small tire/soil contact surface, improper inflation pressure, and high axle load) intensifies the compaction problem (Canillas and Salokhe, 2001), both on the surface and subsurface.

Aluminum saturation in the exchange complex increased with soil depth and was considered high (> 20 %), according to the CQFSRS/SC (2004), at the depth of 0.25 m for both rootstocks (Figures 2c and 2d). There was a lower Al saturation at a distance of 1.5 m from the plant row due to positioning of the fertilizers applied (NPK), always under projection of the tree canopy, where high levels of basic cations occur, mainly K, thereby increasing base saturation. High Al saturation has commonly been found in Brazilian soils, which show the need for liming to amend soil pH and neutralize Al so as not to restrict plant development (Raij, 2010).

The correlation between density, specific surface area, and specific length of roots occurred ($p<0.05$) in a very consistent manner (Table 1). Root density of rootstocks was affected by the incidence of compacted regions and by exchangeable Al saturation along the soil profile, and both rootstocks exhibited similar behavior (Figures 2e and 2f).

There was higher root density in the 0.00-0.30 m layer; a decrease in depth was accompanied by an increase in Al saturation in the exchange complex. Laterally, there was a reduction in root density of the 'Okinawa' and 'Nemaguard' rootstocks (from 50 to 60 %) due to the occurrence of a region of compacted soil in the 0.05-0.25 m layer at 1.8 to 3.0 m from the plant row, which corresponds to the place of highest concentration of machinery traffic for performing the technical itinerary of the crop. The greater root density in the surface layer of the soil under the projection of the plant canopy was mainly due to better fertility conditions in this layer. These results are in agreement with Vercambre et al. (2003), which showed that the root system of peach trees is more extensive up to 0.30 m and operates up to 3 m deep, as long as there are no limiting factors. The lower frequency of deep roots may partially be attributed to the high saturation of CEC by $Al^{3+}$, which

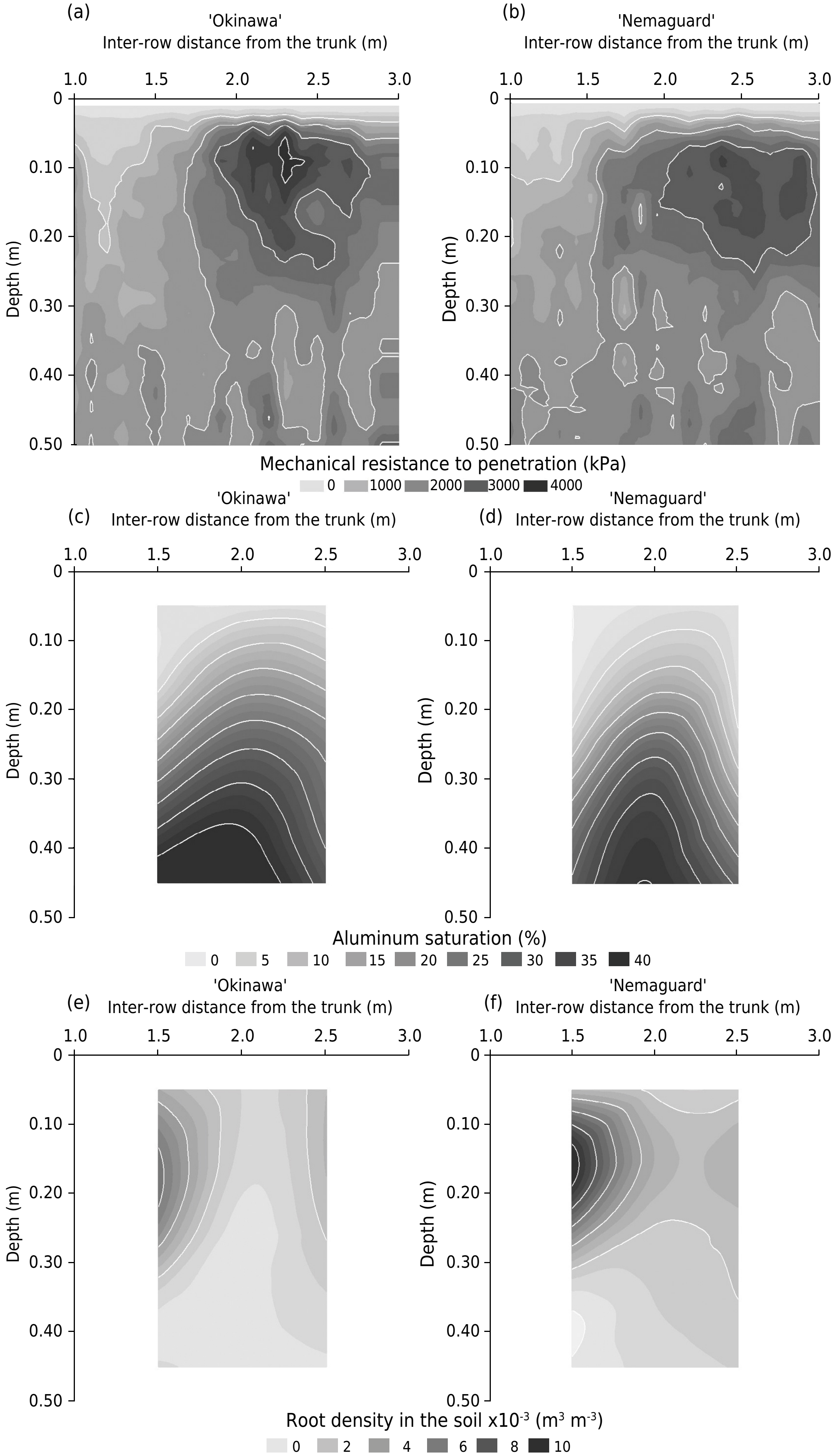


**Figure 2.** Soil mechanical resistance to penetration (a, b), aluminum saturation (c, d), and root density (e, f) in the soil of the inter-row of an orchard of 'Maciel' peach grafted onto 'Okinawa' and 'Nemaguard', respectively.

**Table 1.** Spearman correlation coefficients between soil properties and root distribution in the soil of 'Maciel' peach trees grafted onto 'Okinawa' and 'Nemaguard'

| Variable | RD | SSAR | SLR | V | m | pH($H_2O$) | P Mehlich-1 | K Mehlich-1 |
|---|---|---|---|---|---|---|---|---|
| RP | -0.15 | -0.10 | -0.05 | 0.09 | -0.11 | 0.11 | < -0.01 | -0.34 |
| RD | | 0.97* | 0.91* | 0.39* | -0.41* | 0.39* | 0.37* | 0.27* |
| SSAR | | | 0.98* | 0.40* | -0.42* | 0.40* | 0.35* | 0.21* |
| SLR | | | | 0.39* | -0.42* | 0.39* | 0.31* | 0.17 |
| V | | | | | -0.97* | 0.95* | 0.82* | 0.34* |
| m | | | | | | -0.95* | -0.82* | -0.31* |

*: significant correlation at $p<0.05$. When significant, the pair of variables with positive correlation increase jointly; with negative correlation, one variable increases and the other decreases. When there is no significance, the variables do not exhibit correlation. RD: root density ($10^{-3}$ $m^3$ $m^{-3}$); SSAR: specific surface area of roots ($m^2$ $m^{-3}$); SLR: specific length of roots (m $m^{-3}$); RP: mechanical resistance to penetration; V: base saturation; m: aluminum saturation.

is in agreement with Panda et al. (2009), since Al inhibits growth of the root system by its toxic effect.

There was a reduction in the frequency of thick roots (Ø >2 mm) in the samples collected in compacted soil areas and increasing soil depth (Figures 3 and 4). This decrease was probably due to impediments caused by an increase in soil mechanical resistance to penetration and an increase in Al saturation at greater depth in the soil (Figure 2). The inhibition of primary root growth by soil compaction (Bengough et al., 2011) and Al toxicity (Panda et al., 2009) leads to a reduction in secondary root growth, reducing the rate of thick roots.

Root distribution was correlated ($p<0.05$) with soil chemical properties (Table 1). There were positive correlations between root distribution and base saturation and levels of available P and K in the soil, and a negative correlation between root distribution and Al saturation. Therefore, greater root density occurs where there is greater soil fertility, which is in agreement with the results obtained by Vercambre et al. (2003) and Hodge et al. (2009). Resistance to penetration was correlate with root distribution in the 0.00-0.35 m layer, where greater compaction occurred, which exhibited a correlation coefficient of -0.37 ($p=0.006$) with root density, and -0.27 ($p=0.049$) with specific surface area of the roots.

Root systems rarely encounter uniform resistance to penetration throughout the profile, and this has important implications for how plants deal with mechanical resistance to penetration in the natural environment. When there is an impediment in the subsurface, there is an increase in surface rooting, increasing the formation of lateral roots as compensation. But this behavior was not observed in cases with impairment in vertical layers (Clark et al., 2003), a type of compaction often found in orchards (van Dijck and van Asch, 2002; Minatel et al., 2006; Tolon-Becerra et al., 2010; Müller et al., 2011, Tolón-Becerra et al., 2012; Medeiros et al., 2013). Roots are flexible enough to take advantage of cracks and portions of soil with low resistance, and strong enough to grow in regions with high resistance to penetration. Root penetration in compacted layers is affected by gradients of soil resistance to penetration (Jin et al., 2013). Another factor to be considered is the existence of cracks in compacted soil, generated during drying periods, where roots can grow clumped together in these portions of lower RP. This leads to uneven utilization of the soil by roots in the compacted layers and shows that some roots can grow in low RP levels of compacted soil (Clark et al., 2003).

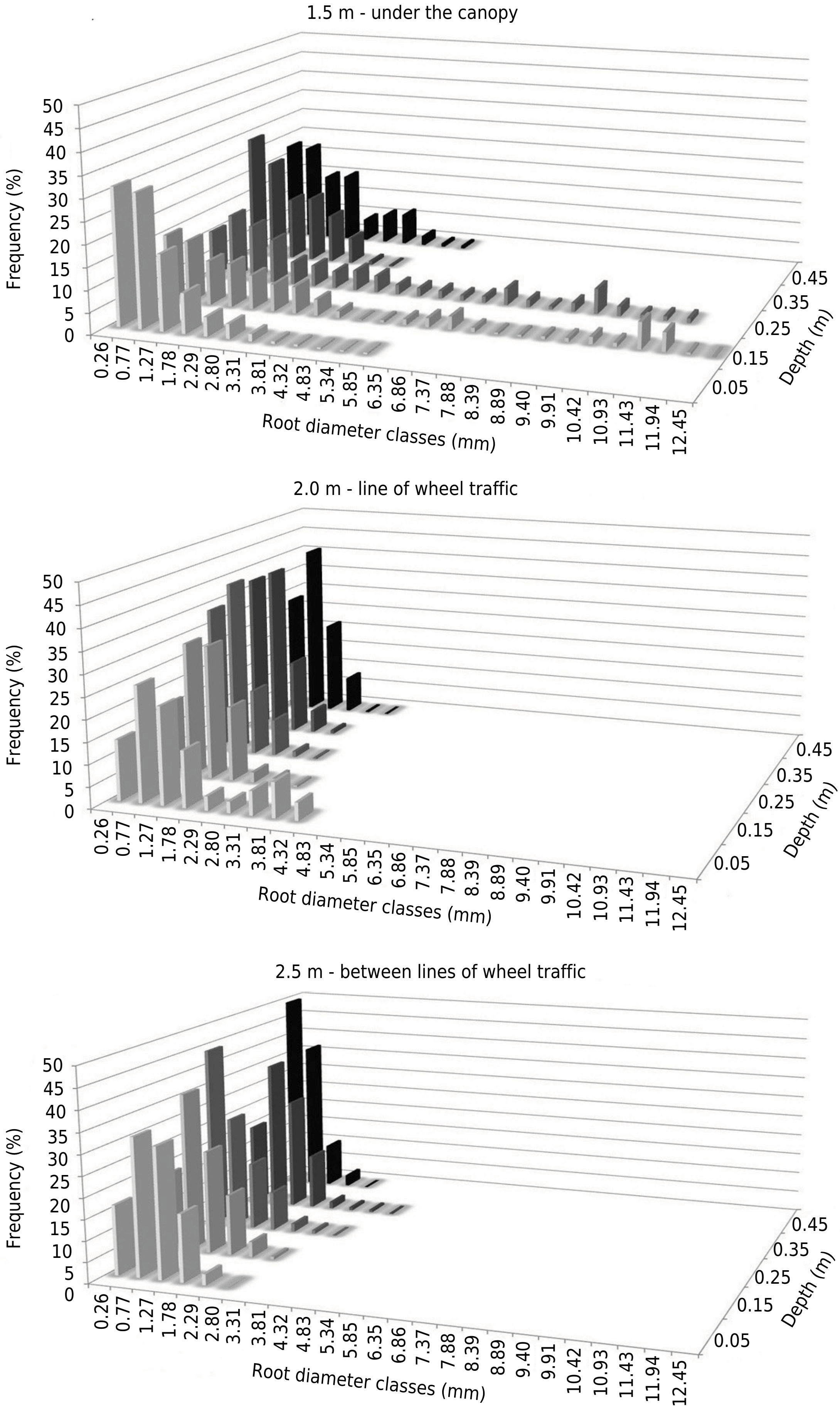


**Figure 3.** Frequency of root volumes for diameter classes and collection depths under the canopy, in the traffic line of the wheel sets, and in the portion between wheel sets of an orchard of ‘Maciel’ peach grafted onto ‘Okinawa’.

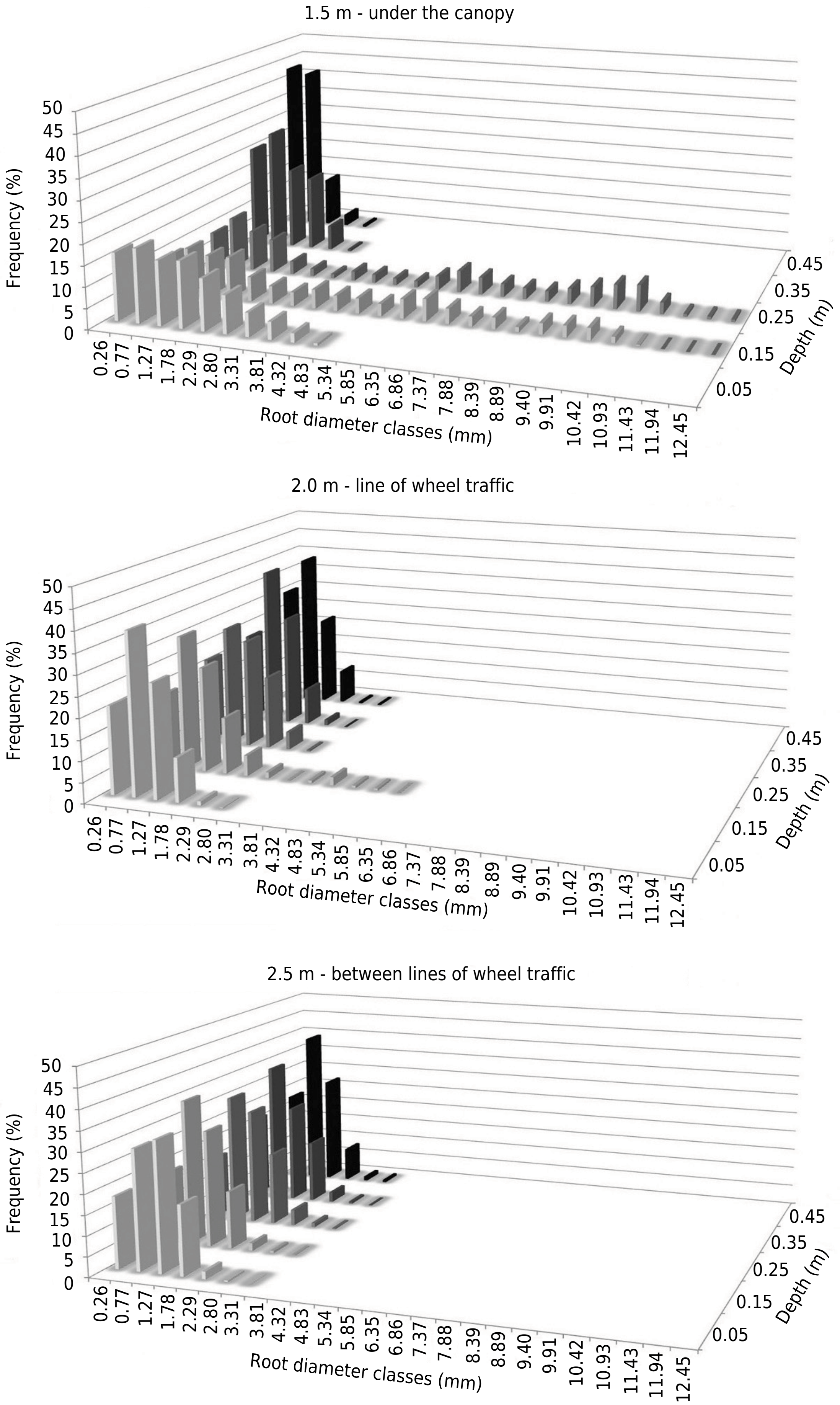


**Figure 4.** Frequency of root volumes for diameter classes and collection depths under the canopy, in the traffic line of the wheel sets, and in the portion between wheel sets of an orchard of 'Maciel' peach grafted onto 'Nemaguard'.

## CONCLUSIONS

The distribution of peach tree roots is determined by the presence of aluminum and resistance to penetration in the surface layer (0.35 m), wherein greatest root growth occurs.

The compacted portion of the inter-row limits lateral distribution of the root system of this species, while aluminum saturation in the exchange complex limits distribution at greater depth. There is, therefore, a decrease in thick roots (Ø >2.0 mm) in regions of compacted soil with high aluminum saturation.

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