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Effect of soil compaction on aerial and root growth of *Erythrina velutina* Willd.

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Compaction can be a triggering factor for a process of soil degradation and formation of degraded areas. Understanding plant development in soils compacted is of fundamental importance, since they allow to identify species able to resist the limiting condition of the compaction, being able to be indicated to recover degraded areas that have compacted soils as limiting factor. The objective of this study was to evaluate the initial aerial and root growth of *Erythrina velutina* in soils subjected to different levels of compaction. The experiment was conducted in a greenhouse located at UECIA/UFRN. A Yellow Latosol of Frankish-sandy texture, from an area of the Jundiaí Agricultural School, was used in pots formed by three overlapping polyvinyl chloride (PVC) rings, 10 cm in diameter and 25 cm in height, with the central ring being compacted. The experimental design was a randomized block design, with six replications, and four levels of soil compaction (1.35, 1.45, 1.60 and 1.80 kg dm^{-3}) were tested, and the following variables: diameter, height, number of leaves, dry mass of shoot and root system in each layer of the columns. The physical impediment in subsurface altered the aerial growth of the seedlings of *E. velutina* being this reduction more expressive for the dry mass variable of the aerial part. In relation to the root system, *E. velutina* showed to be a susceptible species to the effects of soil compaction and morphological changes were observed in the roots in soils with a density greater than or equal to 1.45 kg dm^{-3}.

Key words: Root system, soil density, soil management, recovery of degraded areas.

INTRODUCTION

There are currently alot of study soil compaction by effecting limiting root growth of plants. Plants are the source of life in the living world. They perform many ecological functions in their environment, and they shape the life of living things in the environment where they live. The life of living things in the world is directly or indirectly dependent on plants (Cetin, 2013, 2016; Sevik and Cetin, 2015; Guney et al., 2016; Yigit et al., 2016a, 2016b). The

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ability of plants to fulfil their functions primarily depends on the availability of appropriate climatic and edaphic conditions (Cetin and Sevik, 2016; Guney et al., 2016, 2017; Cetin et al., 2017a). Therefore, soil is one of the absolutely necessary conditions for plant existence, which is essential for the life of living things.

The soil is defined as “the part of the solid earth that has been altered by the loosening of the earth, humus formation and chemical decomposition, by the transport of humidification and chemical decomposition products” (Cetin and Sevik, 2016; Sevik et al., 2016, 2017a, 2017b; Cetin, 2017; Cetin et al., 2017b; Turkyilmaz et al., 2017; Kuscu et al., 2018). However, when it is examined in detail, the soil is a very complex structure and the biological and biochemical process in the soil is the basis of the terrestrial ecosystem (Cetin and Sevik, 2016; Sevik et al., 2016, 2017a, 2017b; Cetin, 2017; Cetin et al., 2017b; Turkyilmaz et al., 2017; Kuscu et al., 2018). In this respect, it is very important to examine the structural change of the soil and to determine its relation with the plant.

Some studies shows that it examined the change of the soil structure in the forests according to the tree species. An attempt to determine some soil characteristics based on tree species and depth of soil was made within the scope of the study. Soil is important for forest and landscape. Enzymes in the soil structure ensure that they are alive in forest areas (Sevik and Cetin, 2015; Cetin, 2013, 2016; Cetin and Sevik, 2016).

Intensive farming, inadequate management and removal of vegetation such as excessive exploitation of timber resources and the uncontrolled use of fire, have generated several physical problems attributed to the soil world wide (Bargali et al., 1992,1993a; Joshi et al., 1997), which combined with the low capacity for regeneration of Caatinga soils, can lead to increased susceptibility environment and desertification and formation of degraded areas (Melo et al., 2008; Sousa et al., 2012). According to Azevêdo and Azevêdo (2012), the recovery of degraded areas has become a constant concern of researchers in the Northeast region of Brazil.

In the Caatinga, the environmental degradation originating from agricultural activity has been increasing. Potentiated by the edaphoclimatic characteristics of the environment, its irrational use has contributed to the biome degradation (Campos et al., 2016).

According to Tavares et al. (2008), soil compaction can be a triggering factor for degradation and degradation of degraded areas, by reducing water infiltration rate, limiting root growth of plants, lower availability of nutrients, and reduce the avalable pore space in the soil resulted in poor soil microbial population which adversally affct the the litter decomposition (Bargali, 1996; Bargali et al., 1993b, 2015).

An area can be considered degraded, when in the event of a strong impact, loses its capacity of resilience, necessitating mitigating measures to revert to the adverse condition (Martins, 2013). Therefore, solutions should be adopted based on the diagnosis of the degraded area and from the type of degradation. In the case of compaction, in addition to commonly used silvicultural practices, one of the alternatives may be the use of plants that have the aggressive root system (Tavares et al., 2008).

The mulungu (*Erythrina velutina* Willd.), is a native species characteristic of the Caatinga Biome. A pioneer in successional stages, it presents great ecological importance in the colonization of secondary areas, being very used in the recovery of degraded areas (Lorenzi, 2002; Matos and Queiroz, 2009). However, there are no studies that address its development in compacted soils.

It is possible that certain species, due to their specificities can even in compacted soils, establishing, improving the physico-chemical properties of the soil and retrieving the quality of same (Reinert et al., 2008).

These specificities help in the selection of species capable of growing under adverse conditions, and may be indicated to recover degraded areas that have compacted soils as a limiting factor. According to Reichert et al. (2003), soil densities critical to plant development on frankish-sandy soils vary from 1.6 to 1.8 kg dm^{-3}. In no-tillage, a system often used to recover degraded areas, a compaction and an evident problem, always being observed to a greater or lesser degree of intensity (Cardoso and Coutinho, 2013).

With these facts, the overall objective of the study was to evaluate the effect of soil compaction on the initial aerial above-ground and root growth of *E. velutina* in a Yellow Latosol of frankish-sandy texture, submitted to different levels of compaction.

MATERIALS AND METHODS

To conduct this experiment, Yellow Latosol of frankish-sandy texture, from the forest experimental area of the Agricultural School of Jundiaí of the municipality of Macaíba-RN was used.

To obtain a higher soil homogeneity, soil portions of the subsurface layer (B horizon) were collected at a depth between 20.0 and 40.0 cm. Afterwards, the soil was dewormed, air-dried and sieved in 2.0 mm mesh, homogenized and sub-samples were analysed for chemical and physical properties (Table 1).

Based on the chemical analysis, soil correction was not performed due to the high value of base saturation and the absence of aluminium, and only basic fertilization was performed for the installation of the urea, simple superphosphate and potassium chloride in the amounts of 150, 300 and 100 mg dm^{-3}, respectively.

The experiment was conducted in a greenhouse located at the Academic Unit Specialized in Agricultural Sciences (UECIA), Federal University of Rio Grande do Norte, Macaíba-RN. The greenhouse is lined with 1.0 mm mesh nylon mesh and transparent glass fiberglass (minimum temperature of 24°C and maximum of 38°C).

The experimental design was a randomized block with six replicates, containing five seeds per experimental unit, and the effect of soil compaction on the initial growth of *E. velutina* at the densities of 1.35 (no compacted layer), 1.45, 1.60 and 1.80 kg dm^{-3}.

The experimental unit was represented by a polyvinyl chloride

Table 1. Chemical and physical characterization of the soil used in the experiment.

Chemistry	Value
pH in water (1 : 2,5)	5.78
P ($mg.dm^{-3}$)[(1)]	2.00
K^+ ($mg.dm^{-3}$)[(1)]	268.00
Na^+ ($mg.dm^{-3}$)	132.00
Ca^{2+} ($cmol_c.dm^{-3}$)[(2)]	1.18
Mg^{2+} ($cmol_c.dm^{-3}$)[(2)]	0.40
Al^{3+} ($cmol_c.dm^{-3}$)[(2)]	0.00
H+ Al ($cmol_c.dm^{-3}$)[(3)]	0.75
SB ($cmol_c.dm^{-3}$)	2.83
CEC (T) ($cmol_c.dm^{-3}$)	3.58
V (%)	79.05
Physical	
Sand ($g.kg^{-1}$)	688
Clay ($g.kg^{-1}$)	180
Silte ($g.kg^{-1}$)	132
F.C (%)	9.04
P.W.P (%)	7.03

[(1)]Mehlich-1extractor; [(2)]KCl1mol.L^{-1}extractor; [(3)]Calcium acetate 0.5 mol L^{-1}extractor at pH 7.0. SB: Sum of bases; CEC: cation exchange capacity at pH 7.0; V: base saturation; F.C: field capacity; P.W.P: permanent wilting point.

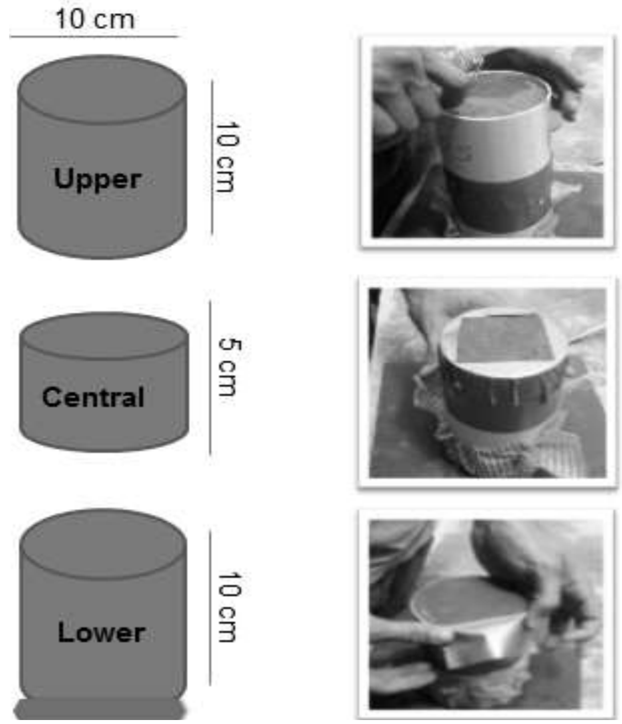

Figure 1. Schematic illustration of the experimental unit used in the experiment.

(PVC) column 10 cm in diameter and 25 cm in height. It was composed of three layers (upper, central and lower), the height of the upper and lower layers being 10 cm; while the central layer was 5 cm, joined by adhesive tape. To close the base of the bottom layer of the column, a multipurpose cloth was used, affixed with rubber alloys (Figure 1).

The upper and lower layers of the PVC column were composed of non-compacted soil; while the central one under soil subjected to four different soil densities. This compaction was done in 2.5 and 2.5 cm layers of soil by blows with a metal plunger, the soil being pressed in the PVC column until the volume corresponding to the desired density inside the central layer of the column.

To avoid root development by the compacted PVC-soil interface (points of least resistance to penetration), the methodology described by Müller et al. (2001), where adhesive tape was placed about 2.0 cm wide, folded from the periphery to the center of the upper surface of the central ring, avoiding the development of the roots contiguous to the wall (Figure 1).

Fifteen days after emergence of the seedlings, thinning was done, leaving only one plant per experimental unit until the end of the data collection, performed 60 days after emergence of the seedlings. Irrigation was performed daily with a graduated cylinder, using the volume of water corresponding to the soil field capacity.

After 60 days of seedling emergence, the height, the collecting diameter at the level of the soil, number of leaves and dry mass of the area and roots at each layer of the experimental unit were recorded. The layers of each column were separated with the help of a stylus, in the three corresponding parts. Then, the soil roots were seperated for each layer and washed out under running water using 1.0 mm sieves to avoid root loss. The shoots and roots were placed in a oven at 65°C for 72 h to determine the dry mass, using an analytical balance.

The data were compared by means of analysis of variance at the 5% probability level and the regression study, using the equation that best fit the untransformed data, using statistical program Assistat 7.7.

RESULTS AND DISCUSSION

The analysis of variance showed that, with the exception of the variable collar diameter (CD) that is not tuned to any regression model, all other variables analyzed were adjusted only to the linear regression model, indicating that the compaction attributed to the subsurface layer of soil interfere significantly in the initial growth *E. velutina* (Table 2).

In relation to the variables height, number of leaves and shoot dry mass of the aerial part, it was observed from the analysis of the regression that, the treatment composed by uncompacted soil showed the best means, having the increase of the density of the soil to the maximum level of compaction, resulting in a reduction of 13.86, 19.72 and 37.85% in the growth of the aforementioned variables, respectively, when compared with the treatment which composed of uncompacted soil, evidencing that the presence of compacted layer in subsurface promotes detriment of the variables that would continue to respond negatively to the compaction effects under larger soil densities (Figure 2).

The results found for the species *E. velutina* corroborate those found by Ribeiro et al. (2010), where the increase

Table 2. Variance analysis and mean values of collar diameter (CD), number of leaves (NL), height (H), shoot dry mass (SDM), and root dry mass in the upper (RDM.U), central (RDM.C) and lower (RDM.L) column of *Eritryna velutina* undergoing different levels of compaction.

SV	DF	Average squares						
		CD	NL	H	SDM	RDM.U	RDM.C	RDM.L
Treatments	3	3.118	8.041	34.621	8.948	0.304	0.047	0.117
Linear	1	6.745^{ns}	21.675*	84.168*	21.819*	0.632*	0.141**	0.348**
Quadratic	1	0.158^{ns}	1.041^{ns}	15.843^{ns}	0.996^{ns}	0.250^{ns}	0.00002^{ns}	0.004^{ns}
Cubic	1	2.451^{ns}	1.408^{ns}	3.852^{ns}	4.029^{ns}	0.310^{ns}	0.001^{ns}	0.00007^{ns}
Blocks	5	1.828^{ns}	1.441^{ns}	10.110^{ns}	2.507^{ns}	0.304^{ns}	0.006^{ns}	0.013^{ns}
Residual error	15	3.322	3.508	18.354	2.783	0.338	0.003	0.004
CV (%)	-	14.83	17.91	14.04	27.52	25.95	26.18	27.67

SV: Source of variation; GL: degrees of freedom; CV: coefficient of variation (%). ns: not significant, **significant at the level of 1% and *significant at the 5% probability level by the F test.

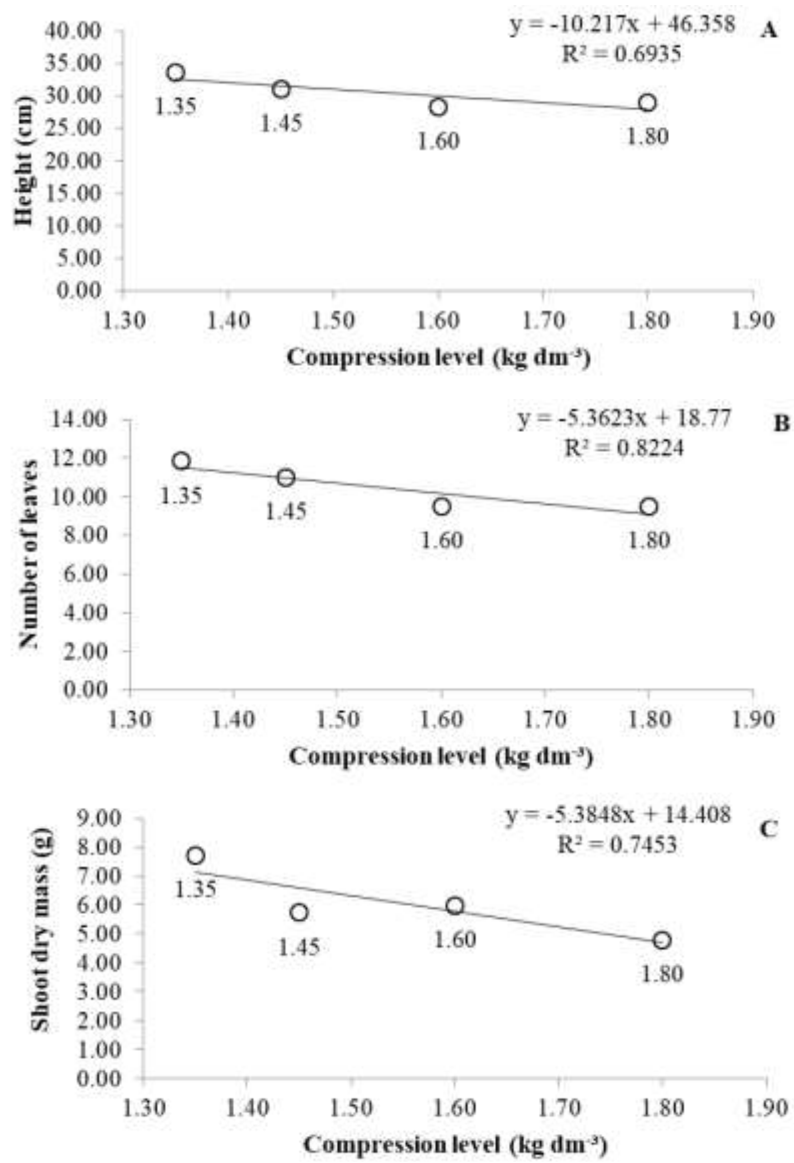

Figure 2. Height (A), number of leaves (B) and shoot dry mass (C) of *Erythrina velutina* plants due to different levels of compaction.

of soil density promoted restrictive effect on growth *Eucalyptus grandis* for the variables height and shoot dry mass, regardless of the type of soil evaluated.

Borges et al. (1986), evaluating the effect of soil compaction in the initial growth of three species of eucalyptus, observed that for the species tested, the negative regression coefficient showed that even small, there was a decrease in the shoot dry mass of the seedlings.

Ohland et al. (2014), also report a linear decreasing trend of the variable height for the species *Jatropha curcas* L., being observed a reduction in plant height of approximately 25% to the highest level of compression tested (1.64 kg dm^{-3}), when compared with lower density (1.08 kg dm^{-3}).

Santos et al. (2012), evaluating the development of *J. curcas* L, depending on the soil density, observed the effect of regression analysis, a linear decrease for all variables analyzed, except for the number of leaves that have increased in function of compaction. Already Pereira Junior et al. (2012), evaluating the growth of roots and shoots of *Moringa oleífera* under conditions of compacted soil, report no significant difference among treatments for the variables diameter, height, shoot and root dry mass, being considered a species relatively resistant to compaction, for not presenting significant effects both on initial growth airspace, as well as in the roots.

In relation to the development of the root system, it was observed that the physical constraint imposed by the compacted layer significantly influenced the root production in all the columns of the vessels and the data was adjusted to the linear regression model (Figure 3).

In the upper column, a linear increase of the root dry mass variable was observed in the aforementioned layer, where the soil density increased at the highest compaction level (T4 - 1.80 kg dm^{-3}) promoted an accumulation of 18.83% of the variable, when compared with the control treatment, composed of uncompacted soil.

Through visual observation, it was verified that the linear increase of roots in the upper column of the experimental unit partially restricted the root system expansion in depth, thus promoting the accumulation of roots in the upper column and the folding of roots (Figure 4).

Reinert et al. (2008), evaluating the physical quality of a Dystrophic Red Latosol after the cultivation of cover plants, reported a normal growth of roots until the limit of density of 1.75 Mg m^{-3}. In the range between 1.75 and 1.85 Mg m^{-3}, restrictions were suggesed on growth, combined with the deformations in the morphology of the roots in medium grade, while above this density, the deformations became more significant, with extensive thickening of the roots, deviations in vertical growth and concentration on the most superficial layer.

The results differ from those observed by Silva et al. (2012), who valuated the effect of compression on the species of *J. curcas* and *Crambe abyssinica*. According to the authors, the physical impediment caused in the subsurface layer in a Red Latosol of medium texture, was not enough to stop the root growth vertically.

Other visual aspect observed was the considerable reduction of the macroporosity of the soil in relation to the increase of the soil compaction, hindering the growth of thick roots and creating a physical layer of resistance to root penetration, thus restricting the vertical expansion of the pivot root along the ground from the density of 1.60 kg dm^{-3}. Moreover, after the processing of the roots, it was possible to observe that the presence of a compacted layer soil densities equal to or greater than 1.60 kg dm^{-3}, caused morphological changes in the growth of the pivot root (Figure 5).

The macroporosity is an important characteristic in soil aeration and drainage of water, as well as the main route to the root growth of plants. When poorly structured or deformed, or can inhibit the development of plants (Camargo and Alleoni, 1997). According to Neves et al. (2005), it is necessary to adequate number of channels that are large enough to allow the roots may penetrate vertically in the ground and develop.

Ohland et al. (2014) evaluated the influence of soil density in the initial development of *J. curcas* L. and reported that densities between 1.50 and 1.64 kg dm^{-3} were considered critical for the development of the species, being noticed, also restricting the expansion of the turnable root in deeper layers, making the most superficial root system in relation to the increase of soil density. The inhibition of root pivoting growth was also observed by Reinert et al. (2008) soil densities greater than 1.85 Mg m^{-3}.

Limitation of pivotal root growth and surface root development in the soil may be a relevant problem for tree species such as *E. velutina*, where inhibition of the root system may reduce the stability of the trees, causing them to be tilted under field conditions.

In central and lower columns of the experimental units, the effect observed was the detriment of the variables, where a large decrease was found in the production of roots of *E. velutina* in the function of increased soil compaction. The highest level of compression tested observed drastic reductions of 64.00 and 75.58% in the production of roots dry mass in the columns above, respectively, being that higher densities to continue promoting the detriment of variables. This restriction has been criticized even in smaller densities of soil as the treatments T2 (1.45 kg dm^{-3}) where a reduction in the production of roots dry mass was 25.5% at the core layer and 31.78% in the layer below the compressed and T3 (1.60 kg dm^{-3}), where the reduction was 39.5 and 55.81%, respectively.

Borges et al. (1986), analyzing the responses of eucalyptus seedlings to soil compaction, observed that the growth of roots of *Eucalyptus camaldolese, Eucalyptus tereticornis* and *Eucalyptus grandis* was nil in

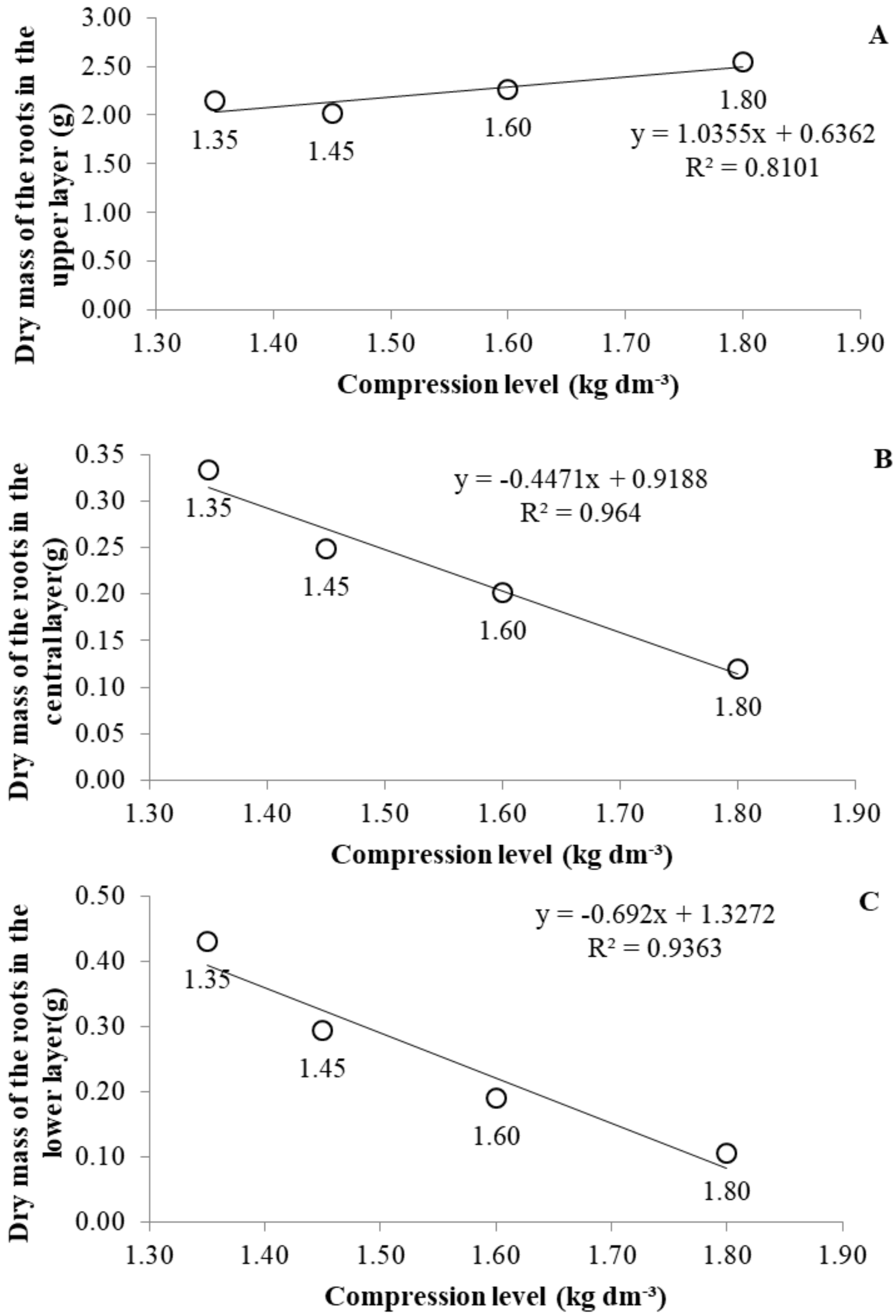

Figure 3. Root dry mass of *Erythrina velutina* in the upper (A), central (B) and lower (C) layers as a function of different levels of soil compaction.

a Dark Red Latosol with 72% of clay soil for densities higher than 1.15 g cm^{-3}, characterizing the species as sensitive to soil compaction.

Differently, from what has been reported in the present study, Pereira Junior et al. (2012) report inexpressive effects of the soil compaction on root growth of *M. oleífera*.

In fact, the pattern of growth of *E. velutina* was not maintained when the species was submitted to the effect of compaction. Such a pattern of growth can be a reflection of morphological changes caused in the root system under conditions of compression, which when associated to lower soil volume exploited, promoted a possible poor nutrition, reflecting in their productivity.

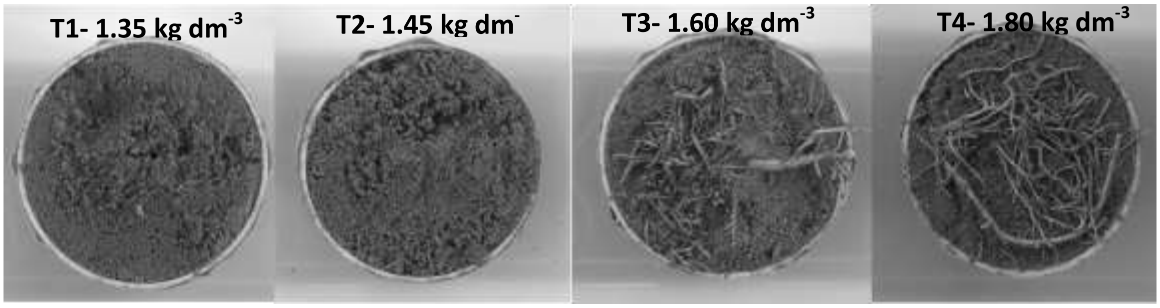

Figure 4. Internal view of the upper layer of the PVC column after sectioning of the experimental units by using a stiletto. Distribution of the apparently unchanged root system in soil without any compacted layer (A), with a compacted layer at a density of 1.45 kg dm^{-3} (B) and 1.60 kg dm^{-3} (C), and apparent accumulation of roots in the surface layer due to subsurface soil compaction at a density of 1.8 kg.dm^{-3} (D).

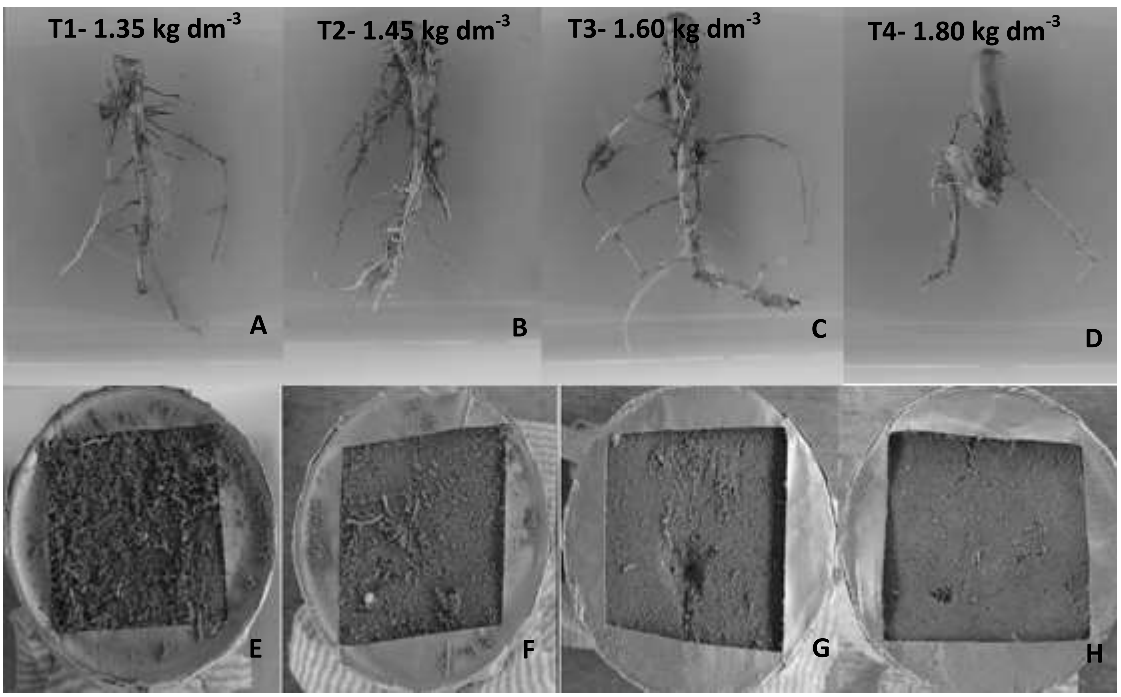

Figure 5. Pivotal root located in the upper layer of the experimental unit after root rooting, apparently without any morphological changes (A and B) and negative effect on the pivoting root as a function of the compacted layer, morphologically altering its structure (C and D). The presence of pivoting root in the central layer under uncompacted soils (E) or when compacted the density of 1.45 kg dm^{-3} (F) and negative effect of the compaction under the pivoting root limiting its growth in the central layer the density 1.60 kg dm^{-3} (G) and 1.80 kg dm^{-3} (H), respectively.

For Alvarenga et al. (1997), physiological and morphological changes of roots make them less efficient in the absorption of nutrients, in this way, the extent of absorption of nutrient is achieved more slowly, consequently, the plants grow less, due to the smaller quantities of absorbed nutrients. According to the same author, the amount of nutrients such as phosphorus, calcium, magnesium, and nitrogen in leguminous, was reduced due to increases in the level of soil compaction. The root system may be the first component affected by compression, because the development of fine roots, where there is a higher rate of absorption of nutrients is impaired (Reichert et al., 2007). This pattern was applied for the present study, having in view that the effects of the soil compaction were much more expressive for the variables related to the root growth than for the variables related to the growth of the plant.

It is believed that in a major period of evaluation, the results would be more expressive, that is, the plant will suffer more accentuated effects of compaction. In this way, further studies were suggested with the species under field conditions, where the evaluation period may be greater.

Finally, an important consideration to be made is that *E. velutina* proved to be a susceptible species to soil compaction effects. Although, considering a pioneer species and recommended in the recomposition of secondary areas, decreasing linear reductions was observed for the variables of the aerial part of the seedlings and a severe impact on the vertical growth of the root system, noticed from equal or higher soil density to 1.45 kg dm^{-3}, indicating that the species should not be recommended for recovery of degraded areas with compacted soil as a limiting factor, unless mechanical practices such as scarification can be made to soften the physical constraint imposed by compacted soils.

Conclusion

The increase in soil density of 1.35 to 1.80 kg dm^{-3} in subsurface layer affects the aerial and root growth of *E. velutina* in the initial phase of plant development, which may be observed in the reeled pivoting root from soil density equal to or greater than 1.60 kg dm^{-3}, not being a species recommended for recovery of degraded areas that have compacted soil as a limiting factor.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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