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CORN ROOT LENGTH DENSITY AND ROOT DIAMETER AS AFFECTED BY SOIL COMPACTION AND SOIL WATER CONTENT

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1 ABSTRACT

Negative effects of soil compaction have been recognized as one of the problems restricting the root system and consequently impairing yields, especially in the Southern Coastal Plain of the USA. Simulations of the root restricting layers in green house studies are necessary for the development of mechanism which alleviates soil compaction problems in these soils. The selection of three distinct bulk densities based on the standard proctor test is also an important factor to determine which bulk density restricts the root layer. The experiment was conducted to assess the root length density and root diameter of the corn (*Zea mays* L.) crop as a function of bulk density and water stress, characterized by the soil density (1.2; 1.4, and 1.6 g cm^{-3}), and two levels of the water content, approximately (70 and 90% field capacity). The statistical design adopted was completely randomized design, with four replicates in a factorial pattern of (3 x 2). The PVC tubes were superimposed with an internal diameter of 20 cm with a height of 40 cm (the upper tube 20 cm, compacted and inferior tube 10 cm), the hardpan with different levels of soil compaction were located between 20 and 30 cm of the depth of the pot. Results showed that: the main effects of subsoil mechanical impedance were observed on the top layer indicating that the plants had to penetrate beyond the favorable soil conditions before root growth was affected from 3.16; 2.41 to 1.37 cm cm^{-3} ($P<0.005$). There was a significant difference at the hardpan layer for the two levels of water and 90% field capacity reduced the root growth from 0.91 to 0.60 cm cm^{-3} ($P<0.005$). The root length density and root diameter were affected by increasing soil bulk density from 1.2 to 1.6 g cm^{-3} which caused penetration resistance to increase to 1.4 MPa. Soil water content of 70% field capacity furnished better root growth in all the layers studied. The increase in root length density resulted in increased root volume. It can also be concluded that the effect of soil compaction impaired the root diameter mostly at the hardpan layer. Soil temperature had detrimental effect on the root growth mostly with higher bulk densities.

KEYWORDS: Soil compaction, water, bulk density, soil strength, root growth.

DURUOHA, C.; PIFFER, C. R.; SILVA, P. A. COMPRIMENTO E DIÂMETRO RADICULAR DO MILHO, EM FUNÇÃO DA COMPACTAÇÃO E DO TEOR DE ÁGUA NO SOLO

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2 RESUMO

Os efeitos negativos da compactação do solo vêm sendo reconhecidos como um dos problemas que restringe o sistema radicular e conseqüentemente, impede a produção agrícola, especialmente no sudoeste dos Estados Unidos. Simulações de camadas de restrição de raízes, em casa de vegetação, são necessárias para desenvolver mecanismos que reduzam problemas de compactação dos solos. A seleção de três diferentes densidades de solo, baseadas no ensaio de Proctor é também um fator importante para determinar qual densidade restringe a penetração da raiz. O experimento foi conduzido para avaliar o comprimento e diâmetro radicular da cultura do milho (*Zea mays* L.), em função da densidade do solo e do estresse hídrico, caracterizado pelas densidades (1,2; 1,4 e 1,6 cm^{-3}) e dois níveis de teor de água (70 e 90 % da capacidade de campo). O método estatístico utilizado foi inteiramente casualizado, com quatro repetições, em arranjo fatorial (3 x 2). Os vasos foram montados em tubos de PVC, com diâmetro interno de 20 cm, sobrepostos, totalizando 40 cm de altura (anel superior com 20 cm e anéis compactado e inferior com 10 cm), a camada com diferentes níveis de solo compactado foi instalada entre 20 e 30 cm de profundidade nos vasos. Os resultados indicaram, através da resistência mecânica que na camada superior as raízes conseguiram penetrar até onde havia condições favoráveis do solo, antes que o sistema radicular fosse afetado de 3,16; 2,41 e 1,37 cm cm^{-3} ($P<0.005$). Ocorreu diferença significativa na camada compactada para os dois níveis de teor de água, sendo que a 90 % da capacidade de campo houve uma redução do crescimento radicular de 0,91 para 0,60 cm cm^{-3} ($P<0,005$). O comprimento e o diâmetro radicular foram afetados pelo aumento da densidade do solo de 1,2 a 1,6 g cm^{-3}, com resistência à penetração de 1.4 MPa. O teor de água de 70 % da capacidade de campo proporcionou maior comprimento radicular em todas as densidades estudadas. O aumento no comprimento radicular resultou em maior volume radicular. Concluiu-se também que os efeitos da compactação do solo prejudicaram o diâmetro radicular, principalmente na camada compactada. A temperatura do solo afetou o crescimento radicular, principalmente nas camadas com densidade elevada.

UNITERMOS: compactação do solo, teor de água, densidade do solo, resistência à penetração, crescimento radicular.

3 INTRODUCTION

Soil compaction can be defined as a reduction in soil volume leading to increased soil bulk density (Hillel, 1980; Marshal & Holmes, 1988). Soil compaction reduces air volume, and causes re-arrangement of soil particles and closer packing of the soil particles (Harris, 1971). Soil compaction, by increasing mechanical impedance, creates adverse growing conditions for roots, as supplies of oxygen, water, and nutrients are reduced (Dexter, 1986; Bengough & Mullins, 1990; Bennie, 1991; Cook et al., 1996).

One soil physical property modified by tillage to alleviate root-restricting layers is soil strength. Soil strength is one of the physical constraints to root growth. In strong soil, roots usually grow thicker (Barley, 1962; Materechera et al., 1991), the rate of elongation slows (Taylor & Ratliff, 1969), and growth is stopped altogether if the soil is too strong.

Bennie (1996), observed relative decrease in root elongation rate with increasing penetration resistance was the same for most plant species. However, Elkins et al. (1997), remarked that pensacola (*Paspalum notatum*) roots were able to penetrate a compacted soil layer that restricted root growth of other species. Whitely and Dexter (1984), noted that root growth of plants with thick tap roots (e.g. sunflower) was more affected in compacted soils than plants with numerous thin seminal roots (e.g. wheat-*Triticum aestivum*). Alvarenga et al. (1996), concluded that root growth of Senna occidentalis was the least affected by mechanical impedance even though it showed low root length density. Mistra et al. (1996), reported that pea (Pisum sativum) root elongation was higher than for cotton (Gossypium hirsutum) and sunflower in compacted soils even though the increase in its root diameter was also higher. This result was attributed to a higher growth pressure exerted by thicker roots. Rosolem et al. (1994), found that soil penetration resistance of 1.42 MPa reduced corn yield, however, root growth was completely affected by 2 MPa. Torres et al. (1996), reported that soil bulk density of 1.4 g cm^{-3} restricted sugarcane root growth in a sandy loam soil. Rao & Narasimham (1988), found that cane yield was impaired by soil bulk density of 1.5 and 1.6 g cm^{-3} in the surface and subsoil, respectively. Similar results were obtained by Srivastava (1984), at a soil density of 1.7 g cm^{-3} for a clay loam soil. The objective of this experiment was to: determine the influence of surface and subsurface compaction on corn shoot and root growth; test the effect of subsoil bulk density and soil water content on corn root growth; determine the effect of subsoil bulk density and soil water content on corn leaf temperature.

4 MATERIAL AND METHODS

A greenhouse experiment was conducted at the Research Greenhouse Facility at Auburn University in Auburn, Alabama (32º 24’N, 85º 54’W). Corn (*Zea mays* L.) variety (DK69-72RR) was selected for this study. A sandy loam soil (kaolinitic, thermic Plinthic Kandiudults) from the Wiregrass Research and Extension Center located in Headland Alabama was used in the study. Initial tests for P, N, and cation exchange capacity were determined on the soil. Phosphorus and potassium levels were in the “high” range of 261 kg ha^{-1} and 115 kg ha^{-1}, respectively, as determined by the Auburn University Soil testing laboratory. Cation exchange capacity averaged 4.6 $cmol_c kg^{-1}$, and soil pH averaged 4.8.

The experiment design was completely randomized with four replications in a factorial pattern of three levels of bulk density (1.2; 1.4 and 1.6 g cm^{-3}) and two levels of soil water content (70 and 90% of field capacity). Selection of two water contents were based on optimum soil condition and permanent wilting point as a criteria to calculate the water depth that should be applied by irrigation (Hansen et al., 1980), and to determine water availability, which is a crucial factor in assessing the suitability of a land area for producing a given crop (Sys et al., 1991). Standard proctor test (ASTM D 4643-00, 2000) was used for defining compactibility at three different compaction levels (5; 15 and 25 blows). Figure 1, shows that this soil can be compacted at relatively low soil water levels.

Pots were constructed of PVC pipes (40 cm lengths, 10 cm internal diameter with a cap bottom to prevent loss of soil from the base). Pipes were divided into three subsections: top layer (0-20 cm) with undisturbed soil; hardpan (20-30 cm) and bottom layer (30-40 cm) with loose soil. A barrier was created with a tape to separate the top and bottom layers to avoid root growth at the edges of the pots and promote the roots to grow through the hardpan. The procedure involves placing a plastic tape approximately 2 cm from the pot edge to act as a barrier to minimize root growth between the soil and edges.

After uniform packing based on the selected bulk density, additional amounts of loose soil were moistened, thoroughly mixed to minimize possible differences in soil fertility and the natural variability in soil physical properties. This soil was used to fill the top and bottom layers. Packing treatments were designed to test the ability of corn roots to penetrate the range of bulk densities chosen. It was assumed that the bulk density of top and bottom layer remained the same.

Pots were placed in a greenhouse and each was planted with three seeds at 2 cm depth. The pots were watered until the soil was saturated. Initial watering was performed on the second day by maintaining pots at approximately 70 and 90% field capacity using ECH_2O -20 probes (Decagon Devices, Pullman, WA). Compatible data loggers were used to monitor the soil water content every 30 minutes. Germination of seeds occurred after 4 days of planting, and plants were thinned to one per pot to prevent competition.

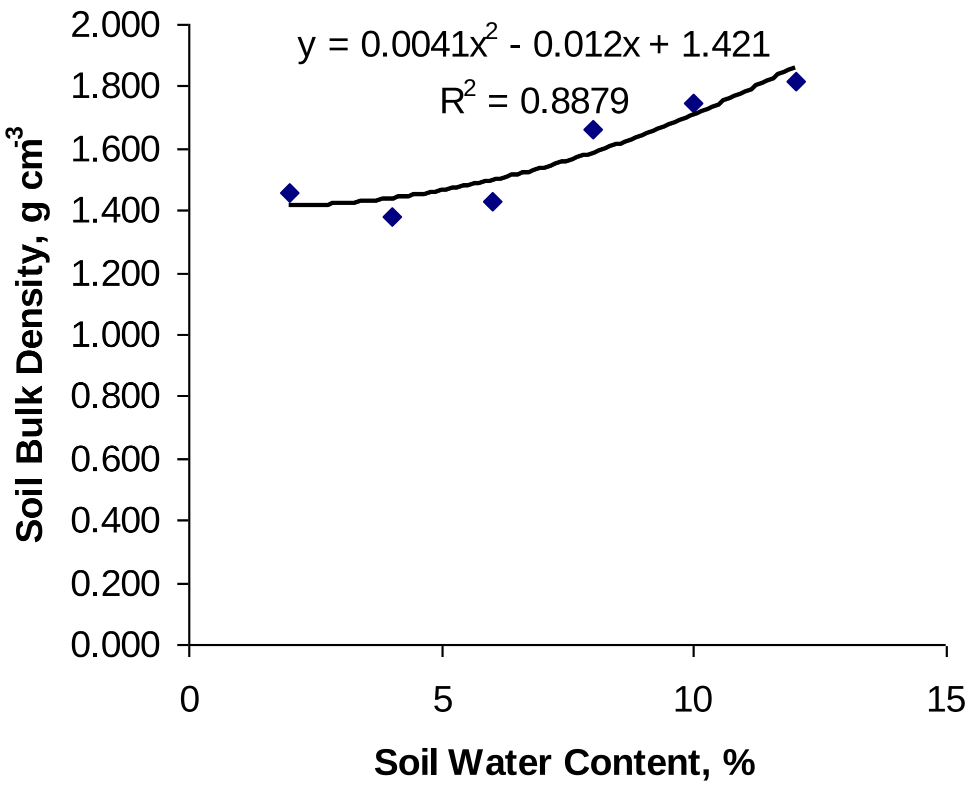

Figure 1. Soil compaction tests determination through the standard proctor test.

Cultural practices of pruning the weeds were undertaken as needed. Pruning process was done manually to avoid rearranging the soil particles on the top layer.

Weekly leaf temperature readings were taken with an infrared thermometer (model 39642-00, Oakton Instruments, Vermon Hills, IL), on the youngest fully extended leaf.

The pots were dismantled after the final harvest and samples obtained from each harvest were oven dried at 55°C for three days. The roots were divided into three layers (top layer, hardpan and bottom layer). The roots were washed and sieved with 1mm screen to prevent loss of the micro roots. Fresh root subsamples (5% by mass) were taken for each layer and submersed in a container with aqueous solution of ethyl alcohol (30%) and water (70%) for root preservation. The root subsamples were used for root analysis. The containers were kept in a cooler at 15°C. The rest of the roots (95%) were oven dried at 55°C for three days for dry matter determination.

The subsamples were scanned on a WinRHIZO™ analysis software (Arsenault et al., 1995; Regent Instruments, Canada) to determine: root length density (cm cm^{-3}), root volume (cm^3) and average root diameter (mm).

After scanning, the root subsamples were oven dried at 55ºC, and weighed. The dry mass of the subsample was added to the dry mass of the bulk root sample to determine total dry root matter.

The statistical package SAS (SAS Institute Inc, 1999) provided the model for the analysis of the factorial design with 4 replicates, and normally distributed data. This analysis of variance provided the standard error difference (SED) for calculation of the appropriate Tukey tests for the comparison of treatments at each harvest. Root weight and length data obtained from different pots at the final harvest were analyzed separately using a similar model.

5 RESULT AND DISCUSSION

3.1 Root Length Density

Table 1 contains analysis of variance result (F test and CV) and the means of the corn root length density for top, hardpan and bottom layer and the total root.

Table 1 show that there was only soil bulk density effect for the root length in the top layer. The highest bulk density 1.6 g cm^{-3} reduced root growth. The increase in mechanical impedance in the hardpan may have led to increase in root length density in the top layer. This effect was in response to growth inhibition observed in the hardpan layer.

Root length density in the hardpan layer was not affected by soil bulk density, but significant soil bulk density versus soil water interaction occurred. The water content of 90% field capacity increased root growth (Table 1).

Plant root growth in response to soil compaction under greenhouse conditions is very complex. Bulk density of 70% field capacity reduced root growth as shown in Table 2. Soils with a bulk density of 1.2 g cm^{-3} for the 90% of field capacity had a greater root development. It was also observed for 70% field capacity that root growth increased. The increase in bulk density for 90% field capacity reduced root proliferation suggesting that poor root penetration in the hardpan layer had an effect on root growth in the layer below. This supports the findings of Eavis (1972), who reported that the increase in bulk density and soil water drastically affected root length density in the hardpan.

3.1.1 Bottom Layer

In the bottom layer (Table 1) the different levels of bulk densities did not affect the root growth. It was observed that water content of 70% of field capacity resulted in increased root growth. The root length density in bottom layer was greater than in the other two layers; pointing that there was adequate growth but the effect was not statistically proved.

3.1.2 Total root length

Root length density (Table 1) was lower in the hardpan layer for the 1.6 g cm^{-3} when compared to the 1.2 and 1.4 g cm^{-3} treatments. However, once the roots penetrated the hardpan layer they were able to grow in the bottom layer. For this reason there were no significant differences in the total root length density between the 1.4 and the 1.6 g cm^{-3} treatments. Kirkegaard, et at. (1992), reported that a reduction of the root length density in the hardpan can be compensated for root growth in zones with lower penetration resistance, and in this manner will not impair the total root length and shoot growth. Soil water content of 70% of field capacity enhanced greater total root length since roots under stress try to explore more soil volume than soil water content of 90% field capacity that had abundant water.

Corn root length was moderately correlated with root volume (Figure 2). It can be verified from Figure 2 that the higher the root length density the higher the root volume. Similar results were reported by Duruoha, (2000).

There was a negative correlation between the root length density and root diameter, meaning that a reduction in root diameter production can lead to higher root length increase probably due to pore size which can impair the root diameter (Figure 3). Also, it can be observed that the scattered dots represent a regression confidence interval.

Materechera et al. (1992), noted that average diameter affects the ability of root growth in soils with low porosity.

Figure 4 shows a positive correlation between root length density and root dry matter. The higher the root length density the higher the root dry matter.

Table 1. Analysis of variance and mean values for corn root length density in the top layers, hardpan, bottom and total as a function of bulk density and water content.

Factor	Root Length Density			
	Top	Hardpan	Bottom	Total
	cm cm^{-3}			
Density (D)				
1.20	3.16 A	0.74 A	4.06 A	7.96 A
1.40	2.41 B	0.81 A	3.13 A	6.36 B
1.60	1.37 C	0.71 A	4.24 A	6.33 B
LSD	0.74	2,434	1.57	1.45
Water (W)				
70%	2.54 A	0.60 B	4.42 A	7.55 A
90%	2.09 A	0.91 A	3.21 B	6.21 B
LSD	0.508	0.13	1.05	0.98
F Value				
Density (D)	0.0001	0.4051	0.1810	0.0153
Water (W)	0.0767	0.0001	0.0269	0.0101
Den.*Water	0.2342	0.0001	0.2840	0.2036
CV	25.09	20.12	32.23	16.59
F Value	8.97	16.14	2.45	4.48

Table 2. The interaction effect of bulk density on the two levels of water content for the corn root length density on the hardpan layer.

Bulk Density	Water content	
	70%	90%
g cm^{-3}	cm cm^{-3}	
1.20	0.38 B	1.08 A
1.40	1.09 A	0.87 B
1.60	0.54 B	0.55 B

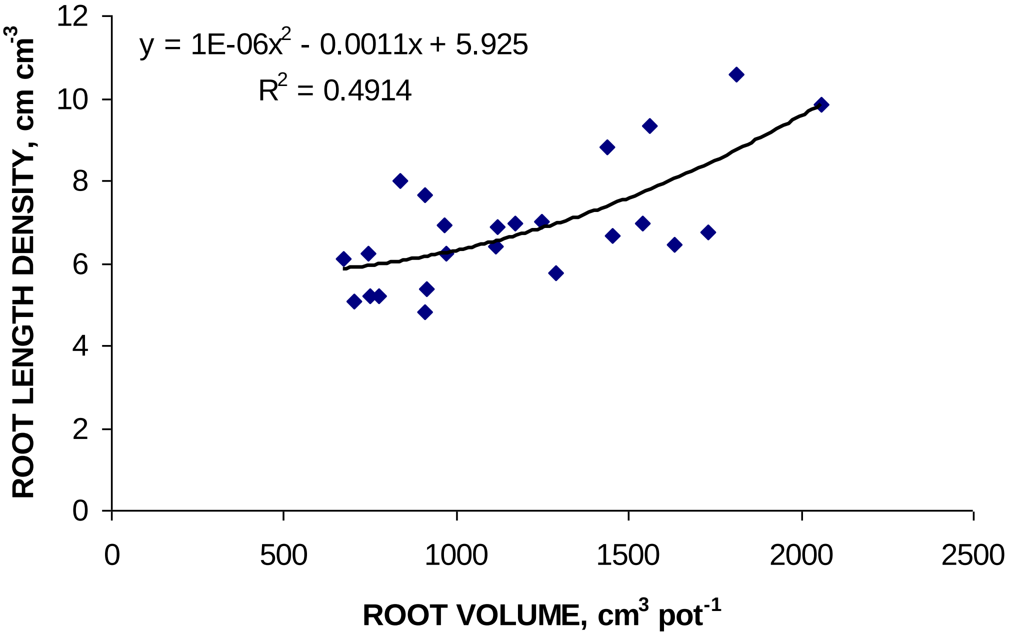

Figure 2. Relationship of root volume with root length density for corn.

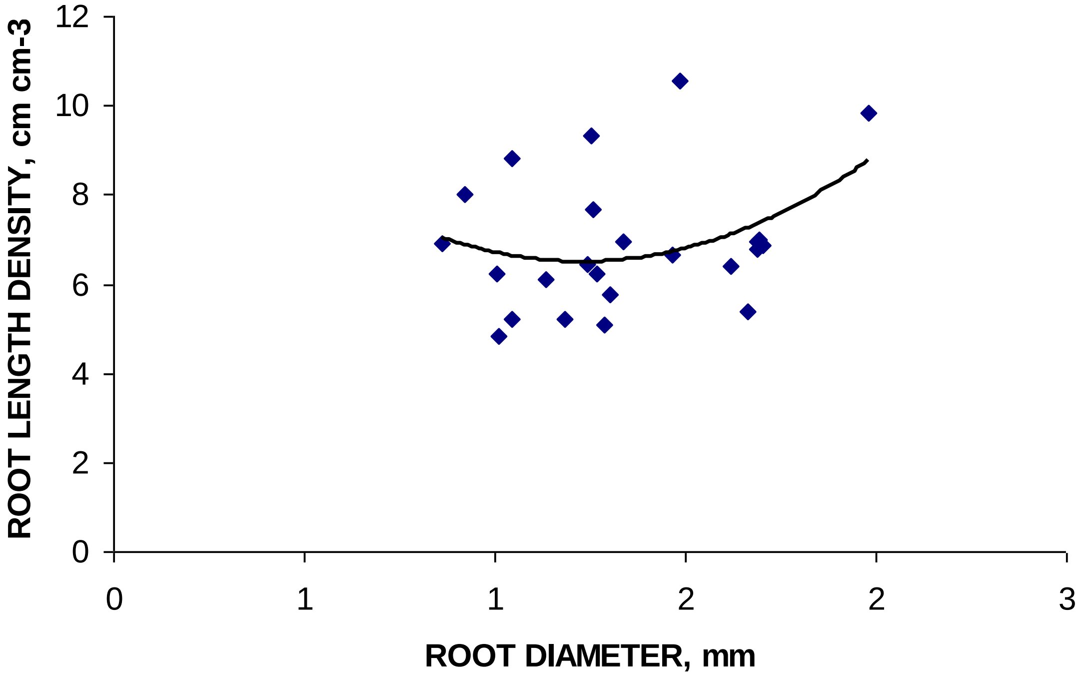

Figure 3. Root length density as affected by root diameter.

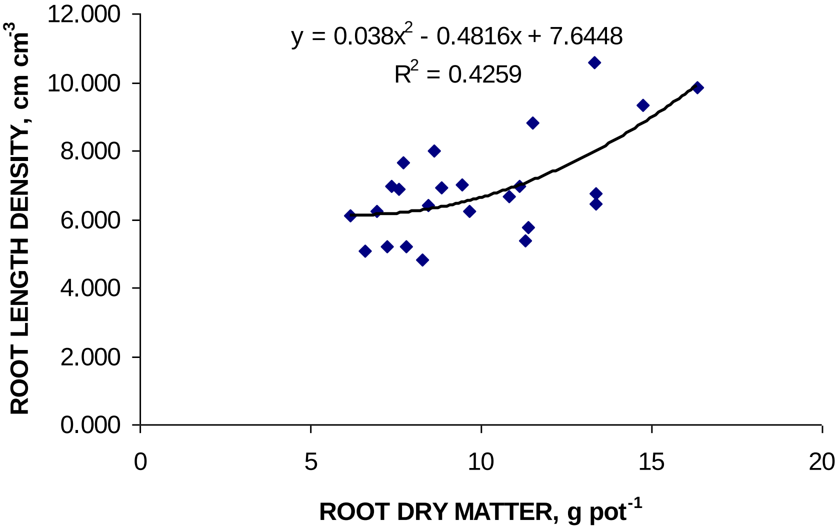

Figure 4. Links between root length density and root dry matter.

3.2 Root diameter

3.2.1 Top layer

In Table 3 (Top layer) it is shown that the soil bulk density and the water content were not significant.

Table 3. Mean Values of the corn root diameter subjected to different bulk densities and water levels.

Factor	Root Diameter (mm)			
	Top	Hardpan	**Bottom**	**Total**
	mm			
Density (D)				
1.20	1.3194 A	2.1346 A	0.9846 A	1.48 A
1.40	1.5645 A	1.5831 B	0.9586 A	1.37 AB
1.60	0.9758 A	1.5758 B	0.9600 A	1.17 B
LSD	0.88	0.517	0.299	0.31
Water (W)				
70%	1.3912 A	2.0006 A	1.0389 A	1.48 A
90%	1.1818 A	1.5230 B	0.8966 A	1.20 B
LSD	0.59	0.35	0.20	0.21
F Value				
Density (D)	0.2557	0.0187	0.9695	0.0581
Water (W)	0.4664	0.0091	0.1549	0.0114
Den.*Water	0.8379	0.4463	0.3677	0.3739
CV	53.57	22.96	24.26	18.068
F Value	0.77	4.05	0.88	3.34

3.2.2 Hardpan Layer

It can be verified that the elements studied had a significant impact on the root diameter. Soil bulk density 1.2 g cm^{-3} enhanced greater root diameter. There were no significant difference between soil bulk density 1.2 and 1.4 g cm^{-3}. This could be attributed to the pore size which determines the ability of roots to penetrate the compacted layer. According to Hatano et al. (1987), there exists dependence between pore size and root growth. Soil water content of 70% of field capacity increased root diameter than 90% field capacity. Roots with water stress seem to explore more soil volume with consequent root thickening.

3.2.3 Bottom Layer

There was no significant difference in soil bulk density or water content in the bottom layer (Table 3). Root growth was also limited in this layer, indicating that the corn plants did not have well developed root systems.

3.2.4 Total root diameter

Total root diameter (Table 3) was significant for water content of 70% field capacity. It can be emphasized here that the 70% field capacity provided the root system with better nutrition, water management and other plant elements. Therefore, this could have a positive effect on the yield.

3.2.5 Leaf temperature

It can be noted in Table 4 that the highest soil bulk density (1.6 g cm^{-3}) caused higher temperatures. Soil temperatures can cause reduced rates of root elongation due to reduction in temperature-sensitive biochemical activity within the meristem apex (Clowes & Stewart, 1967). For all the readings here there were soil temperature effect on the soil bulk density and different levels of water.

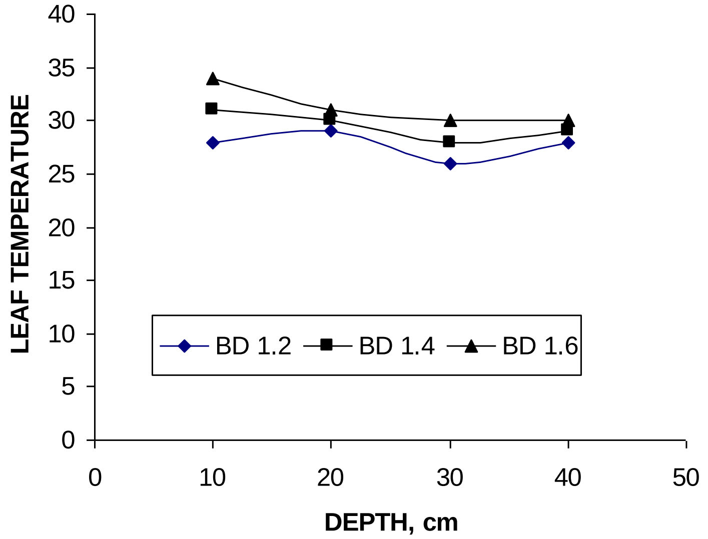

Figure 5. Relationship between total leaf temperatures and total root diameter.

It can be noted from Figure 5 that leaf temperature has a negative impact on the soil depth. This figure shows that the lowest bulk density 1.2 g cm^{-3} had the lowest temperature. An increase in depth for soil bulk density 1.6 g cm^{-3} had a slight decrease in temperature. Also, it can be verified that lower bulk densities have lower temperatures because of macro pores present on the soil.

Table 4 shows that the shoot dry matter was affected by soil compaction. The bulk density of 1.6 g cm^{-3} had a higher yield than 1.2 g cm^{-3}. Also, it was observed that water content of 70% field capacity produced more shoot growth than 90% field capacity.

Table 4. Mean Values of the corn leaf temperatures as a result of different bulk densities and water levels.

Factor	Temperatures					**Shoot Dry Matter**
	——— ^{o}C ———					**—g/pot—**
Density (D)						
	1	2	3	4	TOTAL	
1.20	28.36 C	29.41 B	26.25 C	28.46 C	112 C	15.88 B
1.40	31.21 B	30.01 B	27.91 B	29.30 B	118 B	19.04 A
1.60	33.57 A	31.39 A	30.47 A	30.30 A	126 A	18.78 A
LSD	0.4951	0.7936	1.4377	0.66	1.8973	1.948
Water (D)						
70%	31.08 A	30.57 A	28.07 A	29.43 A	119 A	21.76 A
90%	31.02 A	29.97 B	28.35 A	29.27 A	119 A	14.03 B
LSD	0.3328	0.5334	0.966	0.446	1.275	1.309
------F Value------						
Density (D)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0009
Water (W)	0.6788	0.0277	0.5574	0.4659	0.3698	0.0001
Den.*Water	0.1245	0.3260	0.0849	0.2586	0.1872	0.6477
CV	1.2496	2.0546	3.9934	1.77	1.2506	8.53
F Value	145.77	10.11	12.63	10.69	64.66	35.15

6 CONCLUSIONS

Results presented in this study indicate that mechanical impedance may adversely affect corn root growth at a high bulk density of 1.6 g cm^{-3}. It is likely that mechanical impedance was less important since soil water content of 70% field capacity had higher root growth, and consequently increases root growth (Grable, 1971). Furthermore, visual observation of plant roots concentrating at the interface for the lowest bulk densities clearly suggests that the plants had difficulty penetrating the subsoil as mechanical impedance increased.

The main effects of subsoil mechanical impedance were observed on the hardpan layer indicating that the plants had to penetrate beyond the favorable soil conditions before root growth was affected. The root length density and root diameter were affected by increasing soil bulk density from 1.2 to 1.6 g cm^{-3}. Soil water content of 70% field capacity increased root growth in all the layers studied. The increase in root length density resulted in an increased root volume. Also, it can be concluded that the effect of soil compaction impaired the root diameter mostly at the hardpan layer. Leaf temperature was greater in plants growing in soil with higher bulk densities. It can be concluded that mechanical impedance affected root growth and this manifestation leads to lower root growth in the hardpan. Using soil water to determine root growth in higher soil bulk density is complex since this element has to depend on other soil properties to restrict or enhance root proliferation.

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