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ROOT VOLUME AND DRY MATTER OF PEANUT PLANTS AS A FUNCTION OF SOIL BULK DENSITY AND SOIL WATER STRESS.

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1 ABSTRACT

Soil compaction may be defined as the pressing of soil to make it denser. Soil compaction makes the soil denser, decreases permeability of gas and water exchange as well as alterations in thermal relations, and increases mechanical strength of the soil. Compacted soil can restrict normal root development. Simulations of the root restricting layers in a greenhouse are necessary to develop a mechanism to alleviate 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. This experiment aimed to assess peanut (*Arachis hypogea)* root volume and root dry matter as a function of bulk density and water stress. Three levels of soil density (1.2, 1.4, and 1.6g cm^{-3}), and two levels of the soil water content (70 and 90% of field capacity) were used. Treatments were arranged as completely randomized design, with four replications in a 3x2 factorial scheme. The result showed that peanut yield generally responded favorably to subsurface compaction in the presence of high mechanical impedance. This clearly indicates the ability of this root to penetrate the hardpan with less stress. Root volume was not affected by increase in soil bulk density and this mechanical impedance increased root volume when roots penetrated the barrier with less energy. Root growth below the compacted layer (hardpan), was impaired by the imposed barrier. This stress made it impossible for roots to grow well even in the presence of optimum soil water content. Generally soil water content of 70% field capacity ($P<0.0001$) enhanced greater root proliferation. Nonetheless, soil water content of 90% field capacity in some occasions proved better for root growth. Some of the discrepancies observed were that mechanical impedance is not a good indicator for measuring root growth restriction in greenhouse. Future research can be done using more levels of water to determine the lowest soil water level, which can inhibit plant growth.

KEY WORDS: Soil compaction; water stress; soil bunk; root volume; root growth

DURUOHA, C.; PIFFER, C. R.; SILVA, P. R. A. MATÉRIA SECA E VOLUME DE RAÍZES DE PLANTAS DE AMENDOIM EM FUNÇÃO DA DENSIDADE E DO DÉFICIT DE ÁGUA DO SOLO.

2 RESUMO

O conceito de compactação do solo não inclui apenas a redução do solo, mas também no resultante decréscimo em permeabilidade para trocas gasosas e água, assim como

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alterações em relação térmica e aumento na resistência mecânica do solo. Um solo compactado pode restringir o desenvolvimento radicular normal da planta. 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 presente trabalho foi realizado para avaliar o volume e matéria seca radicular em função da densidade do solo e da disponibilidade hídrica em amendoim (Arachis hypogea). Foram utilizados três níveis de densidade do solo (1,2; 1,4 e 1,6 g cm-3) e dois níveis de teor de água no solo (70 e 90% da capacidade de campo). Os tratamentos foram inteiramente casualizados com quatro repetições em arranjo fatorial (3 x 2). Os resultados sugerem que a produção de amendoim geralmente responde favoravelmente à compactação subsuperficial, na presença de impedância mecânica elevada. Este resultado claramente indica a habilidade da raiz em penetrar na camada de impedimento com menor densidade. O volume radicular não foi afetado pelo aumento da densidade do solo e esta impedância mecânica aumentou o volume radicular quando as raízes penetraram em barreiras com menor compactação. O crescimento radicular abaixo da camada compactada foi afetado pela barreira imposta. Esta compactação impossibilitou que as raízes crescessem mesmo na presença de teor de água ótimo. O teor de água de 70 % da capacidade de campo ($P<0,0001$) proporcionou maior proliferação radicular. Foi observado que a impedância mecânica não é um bom indicador para a avaliação da restrição de crescimento radicular no trabalho em casa de vegetação.

UNITERMOS: compactação do solo, capacidade de campo e crescimento radicular.

3 INTRODUCTION

Soil compaction is a major problem in soil management and crop production wherever agriculture is mechanized. Because the effects of soil compaction are not easily recognized or measured, estimates of its effects on crop production are not reliable. Compaction changes the physical properties of soils by increasing their soil bulk density and soil strength, and may cause reduced infiltration rates of water, poor drainage, reduced availability of water, and reduced air and oxygen supply to roots (Handreck and Black 1994). Because these conditions may modify root growth, and because they may be experienced simultaneously in compacted soil, it is often difficult to differentiate between their effects (Scott-Russell 1977). Soil compaction leads to reduced root growth and as a result, the growth of plants is inhibited. Reduced growth of seedlings in compacted soils has been demonstrated in studies of many plant species (Zisa et al. 1980; Pan and Bassuk 1985; Gilman et al. 1987). Plants growing in compacted soils may be subjected to seasonal cycles of high and low soil strength as these soils dry out and are wetted again. Research has shown that excessive values of soil strength can have detrimental effects on root growth and consequently crop yield (Bowen, 1981).

Miller et al. (1987) concluded that subsoil bulk density ranging from 1.5 to 1.8 Mg m^{-3} was not a factor limiting corn yield on a silt loam, if adequate water and nutrients were available. Schuler and Lowery (1986) reported corn yield decreases up to 40% due partially to subsoil compaction on silty clay. Gaultney et al. (1982) reported a 50% decrease in corn yield when grown in silt loam subsoil compacted after the surface layer had first been removed and then replaced.

Beulter et al. (2004) evaluated the compaction effect in soybean development and concluded the increase in compaction increased the root density and the dry matter in layer of 0.0-0.5m and caused linear decrease in the most compacted layers of 0.05 – 0.10 and 0.10 – 0.15m. There was reduction in soybean yield.

The objectives of this study were: (1) to evaluate the influence of surface and subsurface compactions on the growth and yield of peanut crop; (2) to verify the effect of subsoil bulk density on peanut root growth under controlled climate and water stress conditions; and (3) to evaluate root volume and root dry matter responses of peanut crop to measured mechanical impedance in a range of soil bulk densities in a glasshouse pot trials.

4 MATERIALS AND METHODS

The greenhouse experiment was conducted at the Research Greenhouse Facility at Auburn University in Auburn, Alabama (32° 24´N, 85° 54´W). Peanut (*Arachis hypogeae*) variety “Georgia Green” 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 soil 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). A standard proctor test was used for defining compactibility at three different compaction levels (5, 15 and 25 blows) Refer to ASTM D 4643-00 (2000) which shows the soil had a very high density levels (Figure 1).

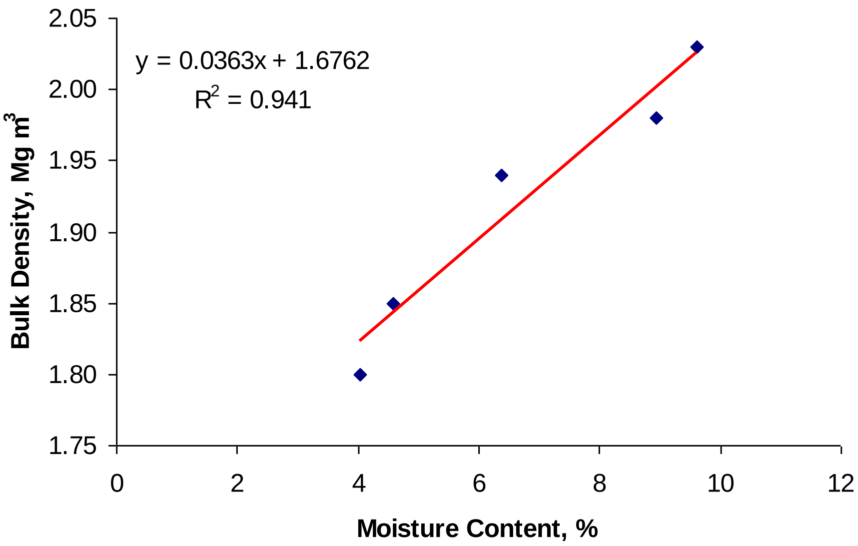

Figure 1. Soil compaction tests determination through the standard proctor tests.

Pots were constructed of PVC pipes (40 cm length, 10 cm internal diameter with a cap bottom to prevent losses of soil from the base). The pipes were divided into three subsections: top layer (0-20cm) 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 peanut root growth at the edges of the pots. The procedure involves placing a plastic tape approximately 2 cm from the pot edges to act as an obstacle to minimize root growth between the soil and edges. This device makes it possible for the roots to try and penetrate the hardpan since it cannot grow through the sides.

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

Pots were placed in a greenhouse and each was planted with three peanut seeds at 2 cm depth. 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). These probes have a resolution of 0.002m^3 m^{-3} (0.1%). Compatible data loggers were used to monitor the soil water content. Germination of seeds occurred after 4 days of planting, and plants were thinned to one per pot to prevent competition.

Cultural practices of pruning the weeds were undertaken as needed. Pruning process was done manually to avoid rearranging of soil particles on the top layer. A modified frame driven penetrometer (Sintech 2/G, 2000) was used for this study that combines attributes from both the American Society of Agricultural Engineers (ASAE, 2004) and American Society for Testing and Materials (ASTM, 1995) standard penetrometer specifications. A cone apex angle of 30^o was chosen and a penetration rate of 1.65 cm s^{-1} was used, instead of 3 (ASAE) or 2 cm s^{-1} (ASTM). It should be noted that cone index (CI) has been shown to be relatively insensitive to penetration speed (Anderson et al., 1980). A constant penetration has been shown to be a more important variable than penetration speed when using a penetrometer to determine mechanical impedance (Hooks and Jansen, 1985). Push rate was maintained within a standard deviation of less than 0.5 cm s^{-1}. Measurements were accomplished before planting and after harvesting and these were replicated four times within each pot. The pots were dismantled after the final harvest. Weekly leaf temperature readings were taken with infrared Mini-TempTest (#39642-0 with an accuracy of 28± 2 and 15±2^{o}C).

The quantities obtained from each harvest were oven-dried at 55^{o}C for three days, and after that the peanut shoot dry matter (DM) yield per pot was determined. The peanut roots were divided into three layers (top layer, hardpan and bottom layer). The roots were washed and sieved with 1mm screen to prevent losses of the micro roots. Fresh root sub samples (5% by mass) were taken from each layer and submersed in a container with aqueous solution of ethyl alcohol (30%) and water (70%) for root preservation. The containers were kept in a cooler at 15^{o}C. The rest of the roots (95%) were oven dried at 55^{o}C for three days for root dry matter determinations.

The subsamples were scanned on a WinRHIZO^{TM} analysis software (Arsenault et al., 1995; Regent Instruments, 2004)[1] to determine peanut root volume (cm^3 pot^{-1}) and average peanut root dry matter (g pot^{-1}).

After scanning, the root sub samples were oven dried at 55^{o}C, and weighted. The dry mass of the root sub sample was added to the dry mass of the bulk root sample for determining the total dry root matter. These data were used to determine the volume, and dry matter of peanut root crop.

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. The obtained data of peanut weight and length from different pots at the final harvest were analyzed separately using a similar model. The interactions among soil bulk density and soil water content and peanut root volume were also evaluated.

5 RESULTS AND DISCUSSION

3.1 Root volume

The root volume is a variable that depends on average root diameter and total root length density, therefore this variable can be seen as compensatory, that is, species which have small root length with high mean diameter can have the same root volume as species which have very high root length and small average root diameter. Table 1 shows the mean root values of peanut volume for the top, hardpan, and bottom layers and the total root volume.

3.1.1 Top layer

It can be observed in Table 1 that increases in soil bulk density lead to an increase in the peanut root volume but the effect was not statistically significant. It was also observed that the two levels of water did not affect root growth.

Table 1. Mean values of the root volume of the peanut crop subjected to different soil bulk densities and water levels

Factor	Peanut root volume (cm^3)			
	Top	**Hardpan**	**Bottom**	**Total**
		——— cm^3 ———		
Density (D)				
1.20	145 A	114 A	78 A	284 A
1.40	210 A	92 B	56 A	345 A
1.60	218 A	44 C	68 A	346 A
LSD	75.231	17.349	29.47	95.20
Water (W)				
70%	199 A	100 A	71 A	333 A
90%	183 A	66 B	63 A	316 A
LSD	50.56	11.66	19.81	63.99
		----F Value----		
Density (D)	0.0446	0.0001	0.1941	0.1898
Water (W)	0.5204	0.0001	0.3608	0.5901
Den.*Water	0.6890	0.0001	0.2447	0.3362
CV	30.9100	16.3500	34.4100	22.9600
F Value	1.7200	53.4500	1.5000	1.2500

Values within row followed by the same letter are not significantly different ($P \leq 0.05$) by the LSD test.

3.1.2 Hardpan layer

The Table 1 shows that an increase in soil bulk density substantially reduced peanut root volume in the hardpan layer. The highest root volume occurred at soil bulk density of 1.2 g cm^{-3} and this could be attributed to soil favorable conditions like nutrients and water. Root volumes in hardpan layer were reduced due to mechanical impedance which affected root growth in this layer. The lowest root volume was observed at soil bulk density of 1.6 g cm^{-3}. The reason can be related to lack of nutrients and other morphological elements that impair root growth. It was also remarkable that the two levels of soil water capacity affected root volume, where soil water content of 70% field capacity level enhanced peanut root volume compared to 90% field capacity level. One of the reasons for this could be the lack of aeration since more water in the soil profile can expel oxygen supply and this has detrimental effects on root growth. Gameda et al. (1987); Marschner, 1986) and Agnew e Carrow (1985) cautioned on the need for adequate water and nutrient supply in the root zones.

The Table 2 demonstrates that an increase in soil bulk density moderately reduced root volume. Soil bulk density of 1.2 and 1.6 g cm^{-3} for soil water content of 70% field capacity increased root volume. Soil water content of 90% field capacity had a detrimental effect on root growth. The reason could be the earlier suggestion in Table 1 for hardpan layer.

Table 2. The interaction effect of soil bulk density on the two levels of water content for the peanut root volume on the hardpan layer

Bulk Density	**Water content**	
	70%	90%
— g cm^{-3} —	——— cm^3 pot^{-1} ———	
1.20	171 A	106 B
1.40	56 A	52 A
1.60	77 A	36 B

Values within row followed by the same letter are not significantly different ($P \leq 0.05$) by the LSD test.

3.1.3 Bottom layer

It was verified in Table 1 that an increase in soil bulk density had no significant effect on the root volume of peanut at the bottom layer. Masle and Farquhar (1988) and Rosolem et al. (1994) observed lower root growth after roots penetrated the compacted layer because they could not recover from the stress they were subjected to. This energy caused high photo assimilated waste which may be the reason for lower root volume for this crop. Also, all the soil water content under investigation did not impair root volume.

3.1.4 Total root volume

Table 1 clearly indicates that an increase in soil bulk density had a proportionate increase in total root volume but the effect was not significant. This could be reflections of no significant level for top and bottom layer. Also, it was noted that soil water contents studied did not affect total root volume.

Figure 2 shows that each root volume increase caused a corresponding increase in root dry mater. Since root volume is a combination of total root length density and average root diameter, any positive response from root volume will absolutely produce equivalent response to root dry matter.

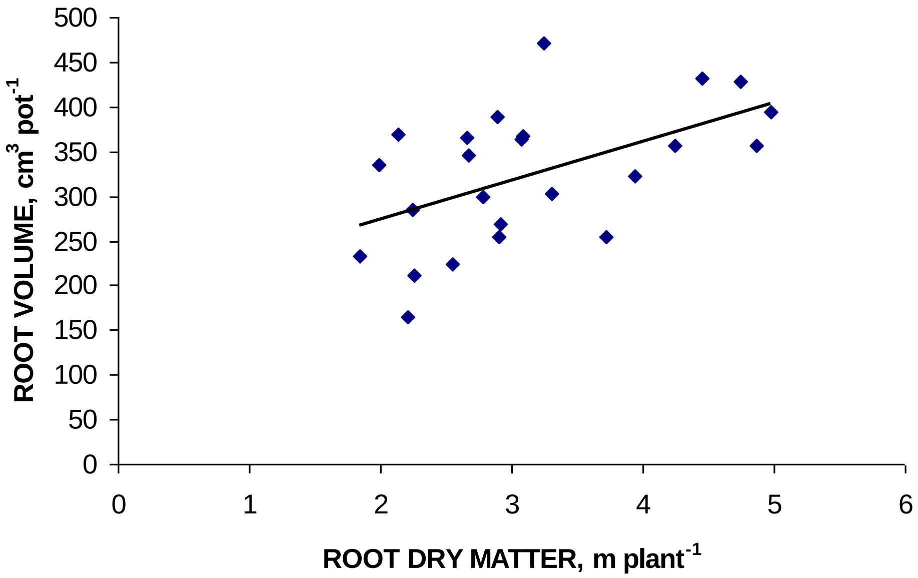

Figure 2. Difference between root volume and root dry mater.

3.2. Root dry matter

3.2.1 Top layer

It can be observed in Table 3 the single effect of soil bulk density. Soil bulk density of 1.6 g cm^{-3} enhanced higher root dry matter production. The effect of mechanical impedance in root growth is masked with optimum soil water content and nutrients. Soil bulk density of 1.2 to 1.4 g cm^{-3} was not significant.

3.2.3 Hardpan layer

Table 3 shows that increase in soil bulk density impaired root dry matter production. The highest soil bulk density (1.6 g cm^{-3}) increased root dry matter production. Soil bulk density 1.2 and 1.4 g cm^{-3} were moderately affected by increased soil bulk density. Pace et al. (1999) got the same result where an increase in soil bulk density in the compacted layer reduced root dry matter production of Crotalaria Juncea L. Also, it was observed that none of the soil water contents were statistically significant. Soil water content of 90% field capacity enhanced higher root proliferation and consequently higher root dry matter. The rate of root elongation increases as soil water content increase. This increase is probably due to sufficient moisture supplied to the aerial portion of the plant, which causes the stomata to open for a greater part of each day. Presumably the soil under investigation acted as a lubricant with high water content which facilitates closeness of the particles. Moraes (1988) agreed with the result.

3.2.4 Bottom layer

Table 3 shows that an increase in soil bulk density did not affect root dry matter. Masle and Farquhar (1988) and Rosolem et al. (1994) observed lower root growth after roots penetrated the compacted layer because they couldn’t recover from the stress they were imposed to. This energy caused high photo assimilated waste which may be the reason for lower root dry matter production for this layer. Also, all the soil water content under investigation did not impair root volume.

3.2.5 Total root dry matter

It can be observed in Table 3 that increased soil bulk density affected total root dry matter. Soil bulk density of 1.6 g cm^{-3} enhanced increased root dry matter production. This result seems to be a reflection of what occurred in top and hardpan layer. Soil bulk density of 1.2 and 1.4 g cm^{-3} did not have any significant effect on total root dry matter. Also, it was observed that none of the soil water contents impacted total root dry matter production. The results agree with Souza et al. (2007) studied the dry matter production in the cotton yield and observed decrease in the compacted layers.

Figure 3 shows that root dry matter depends on number of days after planting. As the number of days after planting increases, there was a corresponding increase in total root dry matter until approximately 25 days after planting. It can be verified that mechanical impedance affected root growth when it approached the hardpan layer and this caused a decrease in root growth and the effect reflected on total root dry matter produced.

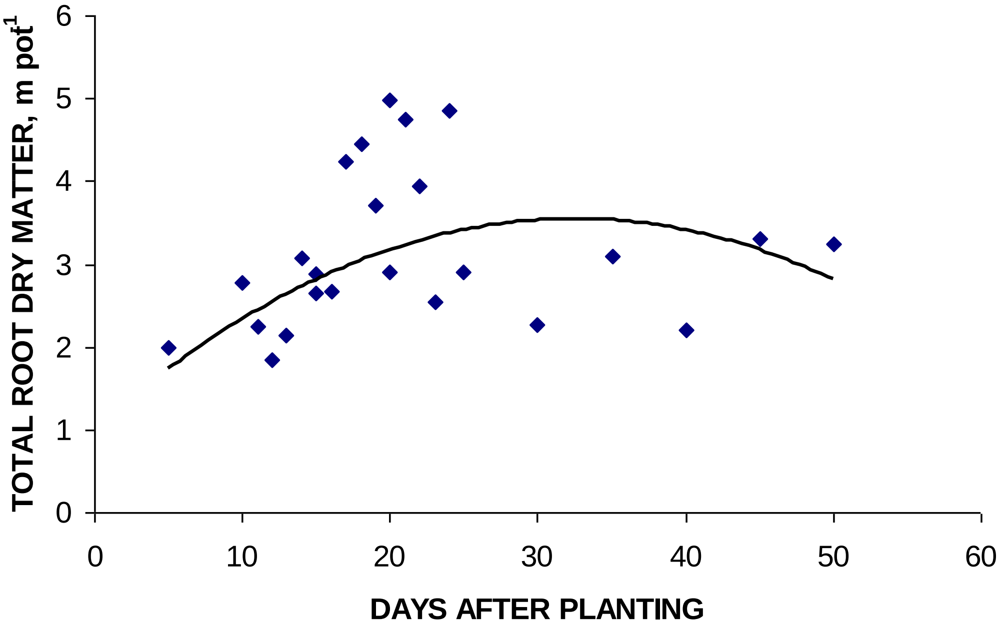

Figure 3. Difference between total root dry matter and days after planting

3.2.6 Penetration resistance

Analyzing Table 3, it can be verified that as soil bulk density increases there was no corresponding increase in penetration resistance. Measurement of mechanical impedance inside a pot is not always reliable, particularly if the soil moisture is at an optimal level. From this result none of the soil bulk density under investigation impaired root growth. This result is in line with what was obtained for root dry matter in the top and hardpan layer. Also, none of the soil water content utilized affected penetration resistance.

Table 3. Analysis of variance and mean values for peanut root dry matter in the top layers, hardpan, bottom and total and cone index as a function of bulk density and water content

Factor	Peanut root dry matter				Cone Index
	Top	Hardpan	Bottom	Total	
	g pot^{-1}				Mpa
Density					
1.20	1.2138 B	0.7325 B	0.6538 A	2.6000 B	1.1701 A
1.40	1.5050 B	0.5000 C	0.6700 A	2.6750 B	1.0708 A
1.60	1.9713 A	1.6525 A	0.5813 A	4.1850 A	1.1858 A
LSD	0.6835	0.1989	0.2601	0.8183	0.564
Water (W)					
70%	1.7792 A	0.7767 B	0.6408 A	3.1967 A	1.0249 A
90%	1.3475 A	1.1333 A	0.6292 A	3.1100 A	1.2595 A
LSD	0.4594	0.1337	0.1748	0.55	0.3791
F Value					
Density (D)	0.0348	0.0001	0.6570	0.0001	0.8539
Water (W)	0.0639	0.0001	0.8900	0.7444	0.2100
Den.*Water	0.7685	0.4138	0.5949	0.8148	0.9142
CV	34.2600	16.3200	32.0900	20.3400	38.7000
F Value	2.5100	53.7900	0.3900	6.3300	0.4400

Values within row followed by the same letter are not significantly different (P≤0.05) by the LSD test.

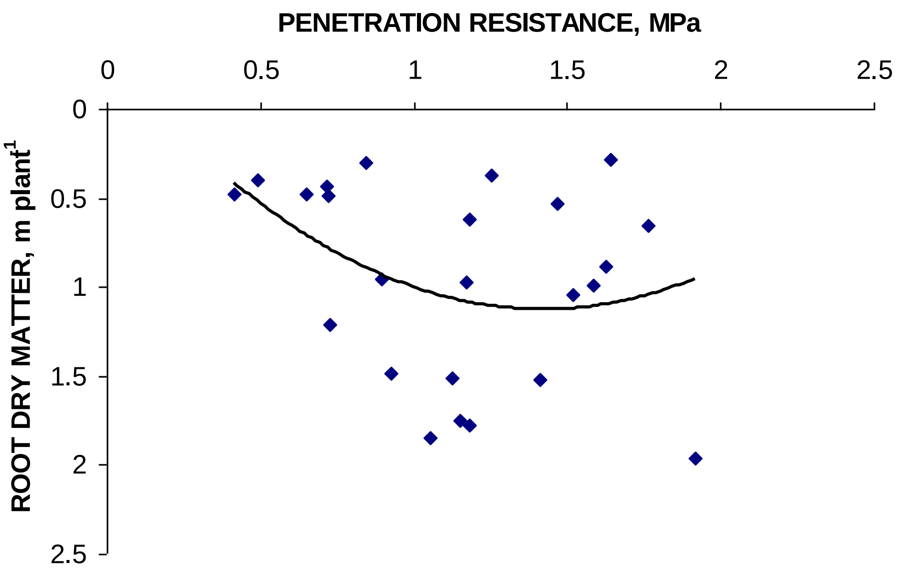

Figure 4. Root dry matter as affected by penetration resistance

Figure 4 shows that as penetration resistance increases, there was an increase in root growth until approximately penetration resistance of 1.5 MPa. After this point, each increase in cone index caused root restriction which invariably reflected on lower root dry matter production.

Figure 5 indicates that as penetration resistance increases from approximately 0.4 to 0.9 MPa, there was a total restriction of root growth (25 to 28 DAP), but it seems the negative effect of soil compaction stabilized between 1.0 to 1.5 MPa (29 DAP), then after this point, the root was able to recover from the stress imposed and there was an increased root growth still with a high cone index values. The effect here reflects results that were obtained with soil bulk density of 1.6 g cm^{-3} for root dry matter in top and hardpan layer (Table 3). It can be noted that here that the effect of mechanical impedance registered here was the opposite effect of what was obtained in Figure 4.

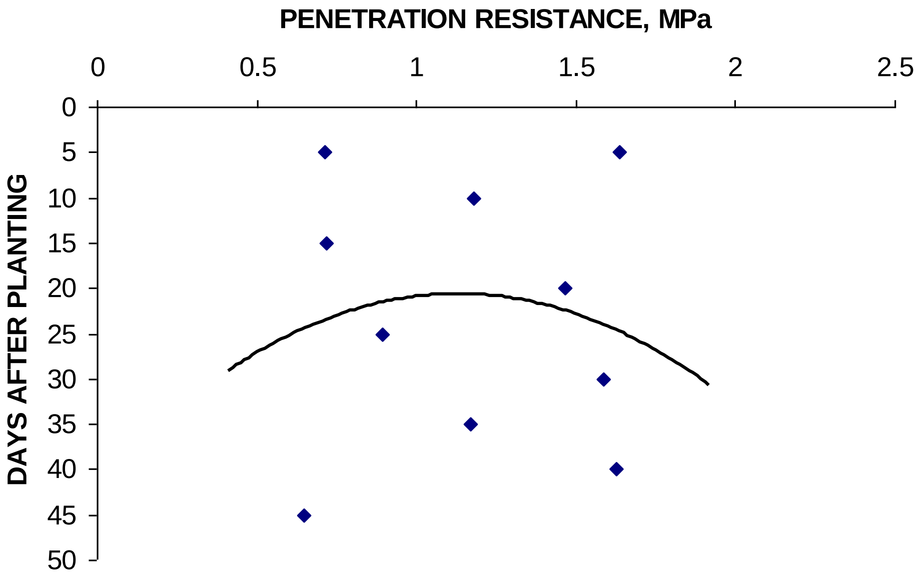

Figure 5. Days after planting as affected by penetration resistance

6 CONCLUSIONS

The result suggests that peanut yield generally responded favorably to subsurface compaction in the presence of high mechanical impedance. This clearly indicates the ability of this root to penetrate the hardpan with less stress as shown in Figure 5. Root volume was not affected by increase in soil bulk density and this mechanical impedance increased root volume when roots penetrated the barrier with less energy. Root growth below the compacted layer (hardpan) was impaired by the barrier imposed. This stress made it impossible for roots to grow well even in the presence of optimum soil water content. Generally soil water content of 70% field capacity ($P<0.0001$) enhanced greater root proliferation. Nonetheless, soil water content of 90% field capacity in some occasions proved better for root growth. Some of the inconsistencies observed here clearly indicate that mechanical impedance is not a good indicator for measuring root growth restriction in a greenhouse trial. Future research can lay more emphasis in using more levels of water to determine the lowest soil water level which can inhibit plant growth.

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