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INFLUENCE OF SOIL COMPACTION LEVELS ON COWPEA PRODUCTION

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ABSTRACT

Cowpea, a short-cycle legume with large production in the North and Northeast regions, has its productive potential limited by edaphic characteristics and degradation processes of soil physical quality, such as compaction. This process may interfere with plant development and productivity by restricting root system growth, aeration, water and nutrient availability. The objective of this work was to analyze the interference of different levels of compaction in the soil physical characteristics, root growth, development of the aerial part and productivity of cowpea. The experiment was conducted in a greenhouse following a completely randomized design with a control (control) and four levels of soil compaction, with four replications. Each experimental unit was composed of PVC tubes composed of a 0.05-m layer of gravel, cotton fabric and a 0.04-m layer of soil. The different levels of compaction were obtained using a proctor socket and a wooden base. Based on the value of penetration resistance (PR) of 1.00 MPa, soil reached the macroporosity considered as critical theresohold for soil aeration. Results indicate that the higher the PR of the soil, the lower the development of the root system and the aerial part. The productive aspects of cowpea presented better results in plants grown in soils with a level of resistance to penetration close to 0.8 MPa.

Palavras-Chave:
características do solo
produtividade
Vigna unguiculata L.

INFLUÊNCIA DE NÍVEIS DE COMPACTAÇÃO DO SOLO NA PRODUÇÃO DE FEIJÃO CAUPI

RESUMO

O feijão caupi, leguminosa de ciclo curto e de ampla produção nas regiões Norte e Nordeste, tem seu potencial produtivo limitado por características edáficas e por processos de degradação da qualidade física do solo, a exemplo da compactação. Esse processo pode interferir no desenvolvimento e produtividade das plantas, ao restringir o crescimento do sistema radicular, a aeração, a disponibilidade de água e de nutrientes. Sendo assim, o trabalho teve por objetivo analisar a interferência de diferentes níveis de compactação em características físicas do solo, no crescimento radicular, no desenvolvimento da parte aérea e na produtividade do feijão caupi. O experimento foi conduzido em casa de vegetação em delineamento inteiramente casualizado composto por um controle (testemunha) e quatro níveis de compactação do solo, com quatro repetições. Cada unidade experimental foi composta por tubos de PVC compostos por uma camada de 0,05 m de brita, tecido de algodão e uma camada de 0,04 m de solo. Os diferentes níveis de compactação foram obtidos utilizando-se soquete de próctor e base de madeira. A partir do valor de resistência à penetração (RP) de 1,00 MPa o solo atingiu a macroporosidade considerada como limite crítico para a aeração do solo. Resultados indicam que quanto maior a RP do solo, menor foi o desenvolvimento do sistema radicular e da parte aérea. Os aspectos produtivos do feijão caupi apresentaram melhores resultados nas plantas cultivadas em solos com nível de resistência à penetração próximo a 0,8 MPa.

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INTRODUCTION

Cowpea (*Vigna unguiculata* L.) is a short-cycle legume, widely distributed worldwide and of great economic, social and dietary importance for the northeastern semiarid population (MARQUES *et al*., 2010). However, the productivity in Brazil and in the Northeast region is relatively lower than the genetic potential of the crop (DUTRA *et al*., 2012), and may be associated with climatic factors, the production system and the absence of adequate technologies, mainly related to nutrition of plants and management as a result of degradation processes of soil physical and chemical quality.

According to Modolo et al. (2011), the physical characteristics of the soil may condition the stability and survival of the crop after emergence, being the compaction one of the main physical attributes that, indirectly, can affect the growth and development of the crops.

This action occurs because compaction consists in modifying the natural structure of the soil by reorganizing the particles and their aggregates, reducing macroporosity and total porosity and increasing microporosity, soil density and penetration resistance (RODRIGUES *et al*., 2014). As a consequence, there may be restrictions on root growth, aeration, availability of water and nutrients, therefore compromising plant development (FARIAS *et al*., 2013).

Among the variables to be considered in the study on the modification of the arrangement of soil particles and aggregates is the soil resistance to penetration (SILVA, 2008), as there is evidence of the direct relationship of this attribute with the vegetative growth and development of the crops (RODRIGUES *et al*., 2014). Pessôa *et al*. (2015) observed that the presence of the compacted soil layer impair the growth components of cowpea and Fernandes *et al*., (2015) found that cultivation of *Vigna unguiculata* in non-mobilized compacted soil restricted the development of the root system, therefore conditioning its growth to the superficial layers.

Because of the importance of investigating the effects of compaction on density, porosity and distribution of soil pores, the objective of this work was to analyze the interference of different levels of compaction on soil physical characteristics, root growth, development of the aerial part and yield of cowpea.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse in Juazeiro *campus* of the Federal University of Vale do São Francisco – UNIVASF, located in the following geographic coordinates: latitude 09º24’S, longitude 40º31’W and altitude of 371 m. According to the Köppen classification, the climate in the region is semiarid tropical, BSwh’ type, characterized as very hot, with low and irregular rainfall.

The experimental design was completely randomized, consisting of a control and four levels of compaction, with four replications, totaling twenty experimental units. Each experimental unit consisted of PVC tubes (0.1 m in diameter and 0.50 m in height) with a layer of 0.05 m of gravel, cotton fabric (for the separation of gravel and soil) and a 0.04 m layer of soil, with open lower end and supported by a concrete base.

In order to obtain the different levels of compaction, a proctor socket and a wooden base (diameter of 0.1 m) were used, which was supported on the soil surface in the tube and had the function of distribute the force applied by the proctor. The force was provided by lifting the inner cylinder of the socket (solid cylinder) to the edge of the outer cylinder (hollow cylinder) and loosening it, causing it to apply a force equivalent to a proctor blow.

By applying different amounts of blows on the soil surface, it was possible to promote the different levels of compaction, expressed in penetration resistance (PR), which was measured using an impact penetrometer (Table 1).

In order to calculate the recommended fertilization for the evaluated crop, chemical analyses (Table 2) of the soil used (Haplic Albaqualf) in the experiment were performed.

For soil characterization purposes, a particle size analysis was performed (DONAGEMA *et al*., 2011) by fractionating the sand classes, according to the US Department of Agriculture (USDA) classification (Table 3).

Table 1. Relationship between the applied mechanical force and the obtained penetration resistance for the definition of treatments

Treatments	Proctor blow	Soil penetration resistance (MPa)
T0	0	0.00
T1	10	0.55
T2	60	1.00
T3	80	1.22
T4	100	1.67

Table 2. Soil chemical characterization

CE	pH	OM	P	C	K	Ca	Mg	Na	S	CEC	V
dS/m		g kg^{-1}	mg dm^{-3}	g kg^{-1}	......................cmol$_c$ dm^{-3}.........................						%
0.56	6.40	6.40	12.00	3.70	0.31	2.50	1.50	0.06	4.37	6.29	69.47

Table 3. Soil particle size with sand class fractioning

Very coarse sand	Coarse sand	medium sand	Fine sand	Very fine sand	Silt	Clay
---------------- g kg^{-1} ----------------						
81.7	103.0	293.5	241.4	123.2	5.9	151.3

At the end of the experiment, particle density (Dp) and bulk density (Ds) were determined and total porosity (TP) was calculated according to Donagema et al. (2011). In addition, macroporosity (Ma) and microporosity (Mi) were estimated according to Stolf *et al*. (2011), following equations 1 and 2, respectively.

$$Ma = 0.650 - \left(\frac{1.341 \times Ds}{Dp}\right) + 0.32 \times sand \quad (1)$$

$$Mi = 0.350 - \left(\frac{0.341 \times Ds}{Dp}\right) + 0.321 \times sand \quad (2)$$

Following preparation of the experimental units, three cowpea (cv. BRS Tumucumaque) seeds were planted. After germination, one of the seedlings was thinned. During the cycle, the cultural treatments necessary to remove pests and diseases were performed.

At the end of the crop cycle, parts of the aerial part and root were oven-dried at 65°C for 72 hours to determine dry matter of the root (RM), aerial part (APM) and total dry mass by summing RM and APM. In addition, it was evaluated other biometric and yield characteristics such as the number of pods per plant, average pod length, average pod mass, number of grains per plant, number of grains per pod, and the grain mass per plant according to Bezerra *et al*. (2014). Moreover, the effective soil depth (ED) was measured according to Cunha *et al*. (2010), given by the soil depth in which 80% of the roots are concentrated and the total chlorophyll that was obtained with the chlorophyll meter ClorofiLOG, model CFL 1030 – Falker.

The analytical results were subjected to analysis of variance by the F test, in which the means were compared by the test of Tukey ($p < 0.05$) with the aid of ASSISTAT beta 7.7 statistical software. For the significant variables, the regression equations that showed the best coefficient of determination were adjusted.

RESULTS AND DISCUSSION

Soil physical characteristics, density, total porosity, macroporosity and microporosity were directly influenced by the different levels of penetration resistance (Table 4).

A significant variation was found in all soil physical characteristics analyzed as a function of the increase in PR value, influencing the increase of density and microporosity and decrease of total porosity, macroporosity and effective depth.

It can be observed through the data shown in Figure 1 that there is relationship between PR and Ds, presenting an increasing linear behavior with high adjustment index ($R^2 > 0.9$) between the related variables. This result corroborates a study by Torres *et al*. (2015) in which a significant increase in PR was observed as soil density increased, showing that, according to Custódio et al. (2015), soil management directly interferes with the mass-volume relationship, since the imposed mechanical compression promotes a rearrangement of soil particles in porous space.

The decreasing linear behavior shown in Figure 2 describes the way the described phenomenon is also reflected in the total porosity of the soil, indicating a reduction in the values of this variable when PR increases. This result agrees with Rocha *et al*. (2015), who also found that increasing soil density and penetration resistance reduced TP.

Table 4. Soil physical characteristics as a function of the different levels of penetration resistance (PR)

PR (MPa)	Ds (g cm^{-3})	PT (m^3 m^{-3})	Ma (m^3 m^{-3})	Mi (m^3 m^{-3})	ED (m)
0.00	1.25 c	50.37 a	0.26 a	0.80 c	0.40 a
0.55	1.39 bc	45.36 ab	0.20 ab	0.82 bc	0.40 a
1.00	1.53 ab	39.69 bc	0.12 bc	0.84 ab	0.13 b
1.22	1.60 a	36.77 c	0.08 c	0.85 a	0.95 c
1.67	1.65 a	35.37 c	0.06 c	0.85 a	0.68 c

Ds: Bulk density; TP: total porosity; Ma: macroporosity; Mi: microporosity; ED: effective depth. * Means followed by the same letter do not differ statistically by the test of Tukey at the 5% probability level.

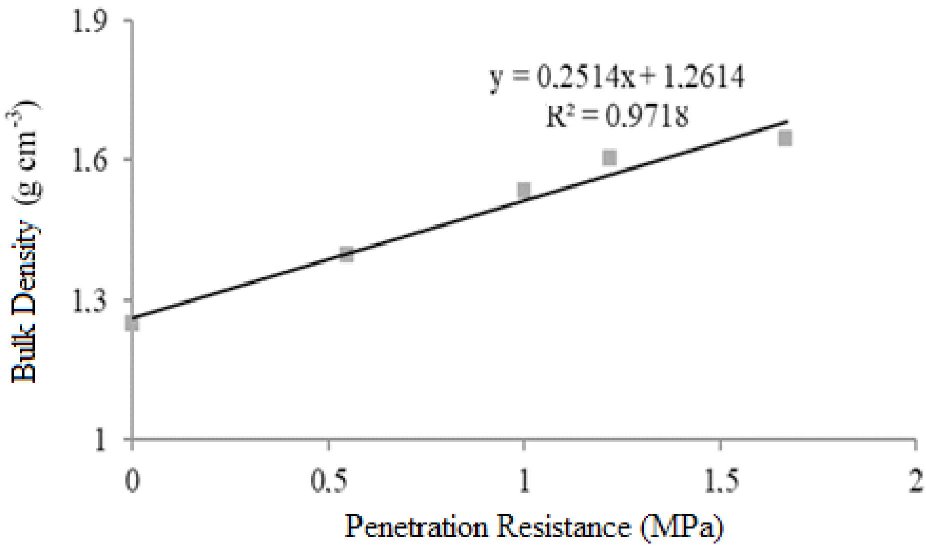

Figure 1. Bulk density as a function of the different levels of PR.

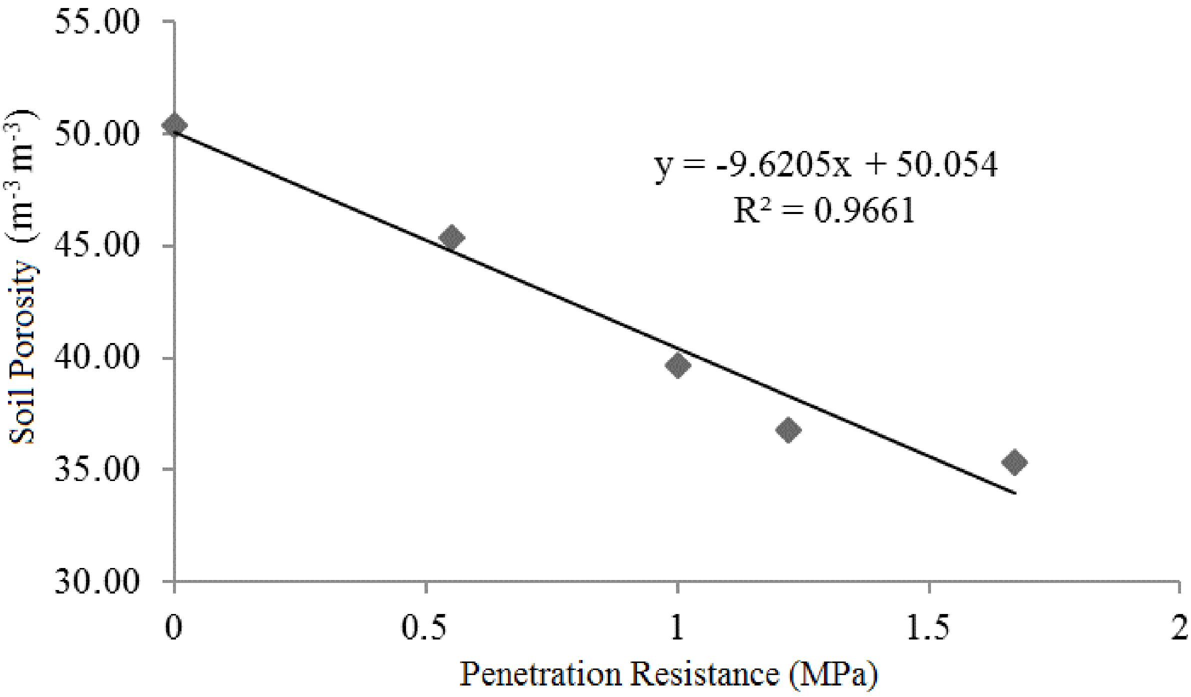

Figure 2. Total porosity as a function of the different levels of PR.

Figure 3 shows the relationships between PR, macroporosity (Ma) and microporosity (Mi). Similar to total porosity, macroporosity had a decreasing linear behavior (Figure 3a), with a high coefficient of determination among the related variables (0.9683), therefore indicating that as penetration resistance increased as a function of soil particles approximation, pore size follows a decreasing trend. On the other hand, the inverse situation was observed in microporosity (Figure 3b), showing an increasing linear behavior and also with a high adjustment index among the related variables (0.9564). According to some authors (REICHERT *et al*., 2001, 2007; THOMASSON, 1978) the 0.10 $m^3\ m^{-3}$ macroporosity has been considered as a critical lower threshold for soil aeration and, according to Table 3, from PR of 1.00 MPa this value was reached. Macroporosity is determined aeration porosity and has an effect on plant development by influencing the diffusion of gases into the root system (STEPNIEWSKI *et al*., 1994; KLEIN *et al*., 2008).

The results obtained in this study corroborate with Marcatto *et al.* (2017) who observed a negative correlation of soil density with macroporosity and a positive correlation with microporosity when studying a Regolithic Neossol, showing that soil compaction reduces the volume of macropores and increases the quantity of micropores.

The results obtained in the study were given that, according to Lima *et al*. (2013) the reduction in the volume occupied by soil mass when compressed by the compression exerted by the management promotes the disintegration of particles, causing them to occupy macropores, thus increasing the amount of micropores.

Plant morphological characteristics: root dry mass (MR), aerial part dry mass (MPA), total dry mass (MT) and effective soil depth (ED) were influenced by different levels of soil penetration resistance (Table 5).

The effective soil depth, that is, the soil depth at which the roots of the plants could develop properly, showed a significant decrease with increasing PR. Only the lowest compaction level (PR 0.55 MPa) was statistically equal to the treatment in which there was no mechanical compression, as observed in Figure 4.

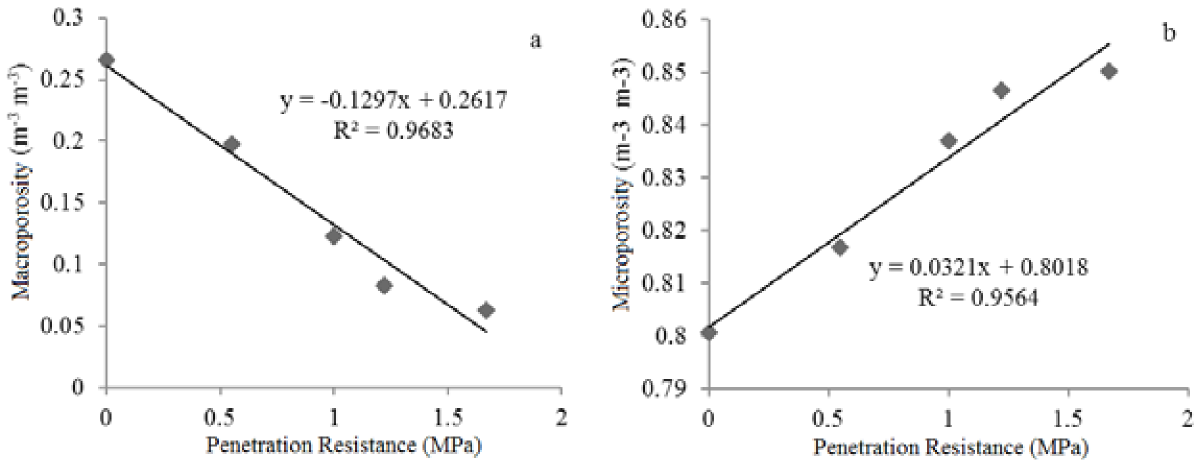

Figure 3. Soil macroporosity (a) and microporosity (b) as a function of different RP values.

Table 5. Plant morphological characteristics as a function of PR levels

PR (MPa)	ED (m)	RM (g)	APM (g)	TM (g)
0.00	0.40 a	10.08 a	20.38 a	30.46a
0.55	0.40 a	6.95 b	14.98 b	22.37b
1.00	0.13 b	7.28 b	11.47bc	18.40c
1.22	0.09 c	6.56 b	8.22c	14.78c
1.67	0.07 c	6.90 b	10.48 c	17.38c

*Means followed by the same letter are not statistically different by the test of Tukey at 5% probability.

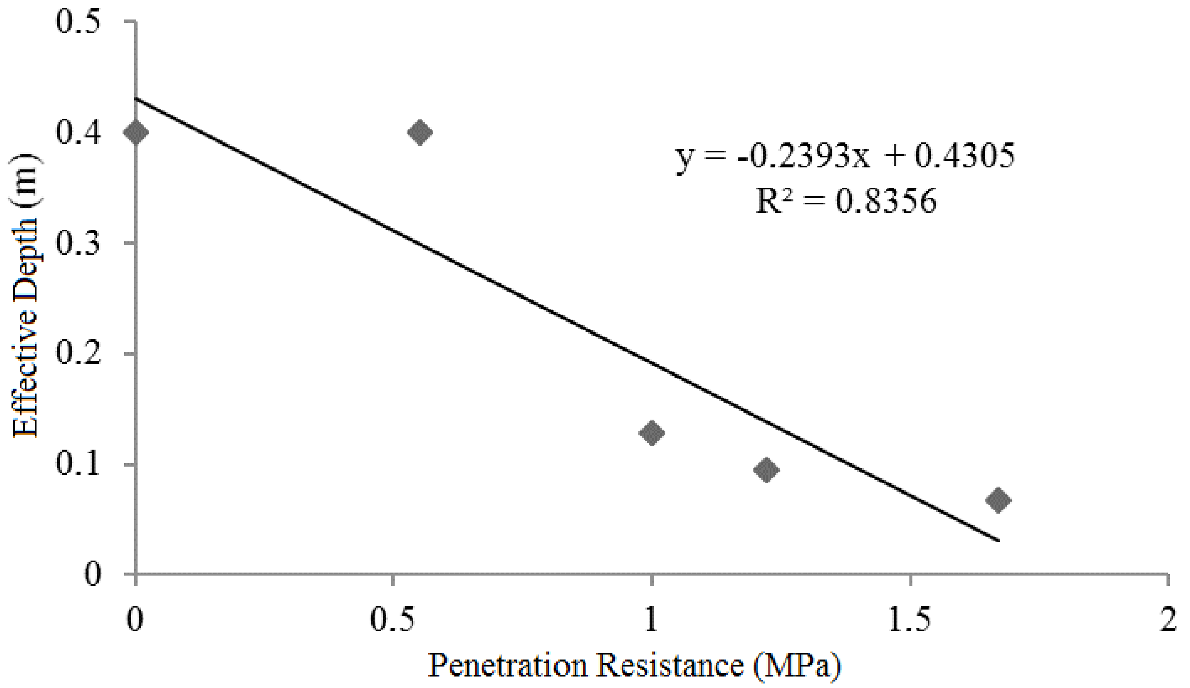

Figure 4. Root effective depth as a function of the different RP levels

The result corroborates with Fernandes *et al*. (2015), who found that in compacted soil, cowpea did not have proper root growth in the 0.0 to 15.0 cm layer and, in general, it rarely exceeded 10.0-cm depth.

This reduction in effective depth inhibits plant development because it occurs simultaneously with a reduction in the radius of action of the plants as it is found in this depth most roots with greater capacity for water absorption and, consequently, of nutrients, which are indispensable for root growth (BIZARI *et al*., 2010; CUNHA *et al*., 2010).

As for root dry mass, only the control differed significantly from the other levels of penetration resistance, showing the highest value. This result is caused by the reduction in the amount of macropores and the increase in bulk density, which interferes with the penetration capacity and development of the plant root system in the soil (MODOLO *et al*., 2011).

Reductions were observed for the values of the variables plant height, aerial part dry mass and total dry mass, which were concomitant with the increase in soil density, since compaction reduces the effective soil depth, impairing the absorption of nutrients essential to biomass accumulation in the aerial part and root system (BIZARI *et al*., 2010).

The plants grown in the treatments with lower compaction levels were more vigorous, a fact shown when 66 days after anthesis, cowpea leaves presented higher indices of chlorophyll A and B (Figures 5a and 5b, respectively).

The results found in this study are explained by considering that soil compaction interferes in the development of the root system through the reduction in density of absorbent hairs, thus decreasing the absorption of water and nutrients such as nitrogen and magnesium. Therefore, according to Targino *et al*. (2017), a significant decrease in chlorophyll synthesis occurs and, consequently, it affects the photosynthetic and metabolic activities of the plant.

Table 6 shows the results regarding the productive characteristics: number of pods (NP), average pod length (APL), average pod mass (APM), number of grains per pod (GP), number of grains per plant (GP) and total grain mass (TGM).

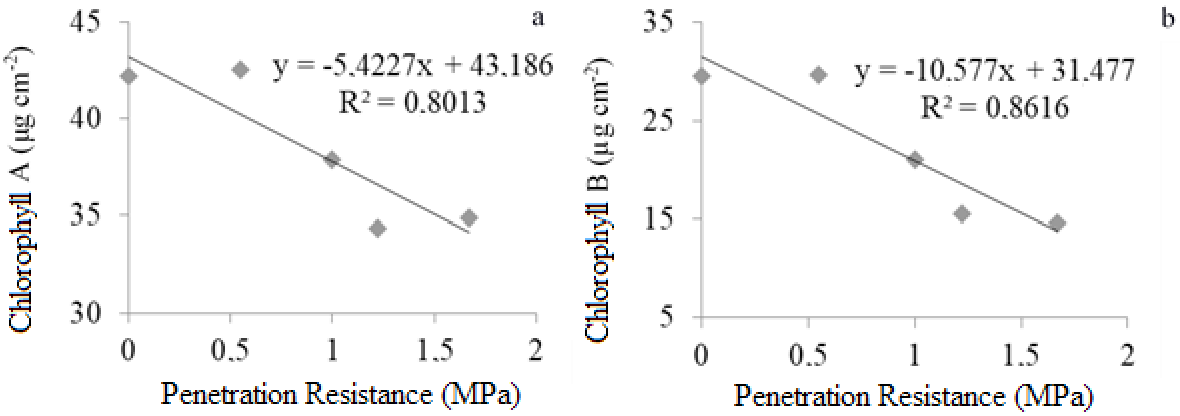

Figure 5. Contents of chlorophyll A (a) and B (b) as a function of the different values of PR.

Table 6. Plant productive characteristics as a function of the different levels of PR

PR (MPa)	NP	APL (cm)	APM (g)	GP	GP	TGM (g)
0.00	1.33 a	15.75 b	2.36 a	3.25 c	4.08 b	1.40 b
0.55	2.67 a	17.64ab	2.62 a	7.62 b	15.62a	3.76 a
1.00	2.33 a	18.67 a	2.69 a	9.75 a	17.00a	4.45 a
1.22	2.67 a	12.40 c	2.53 a	8.25 b	15.01a	3.84 a
1.67	1.67 a	12.85 c	1.09 b	4.00 c	4.00 b	0.68 b

*Means followed by the same letter are not different from each other. The test of Tukey was applied at the 5% level of probability.

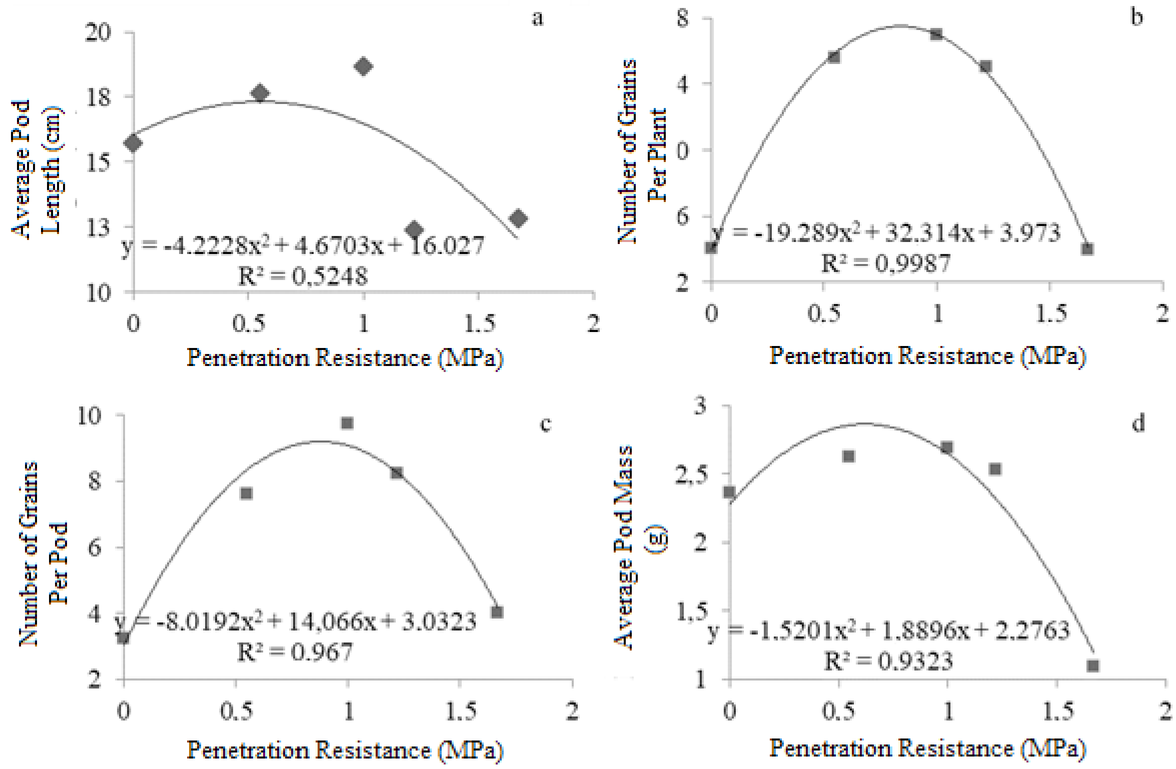

Figure 6. Average pod length (a), number of grains per plant (b), number of grains per pod (c) and average pod mass (d) as a function of different PR values.

The number of pods was not affected by soil compaction, while the other productive characteristics showed better performance in the intermediate treatments, with the maximum PR obtaining lower statistical values than those of other penetration resistances (Figure 6).

Thus, it can be seen that the plants presented better productive performance when subjected to intermediate levels of compaction. In addition, the maximum value of all the aforementioned characteristics occurs when penetration resistance is close to 0.8 Mpa.

The results obtained in the study are from the interference of the compaction levels in the vegetative development, impaired by the deficiency in the absorption of nutrients and water by the plants, thus affecting the dry mass of root and aerial part, which affect productivity (PEREIRA *et al.*, 2014)

However, it should be stressed that the presence of compaction levels is necessary to promote plant stability, without hindering the action of micropores in water retention, thus avoiding excessive drainage and nutrient leaching, interfering with grain production.

CONCLUSIONS

- From the RP value of 1.00 Mpa, the soil reached the macroporosity considered as a critical threshold for aeration
- The higher the resistance to soil penetration, the lower the development of the root system and aerial part.
- The productive aspects of cowpea showed better results in plants grown in soils with penetration resistance level close to 0.8 Mpa.

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