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Efficiency of *Cajanus cajan* in different sowing densities on soil compacting

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This research conducted in the District of Concepción, Concepción Department, Paraguay, involved the use of a randomized complete block design consisting of four treatments and five repetitions. The general objective was to evaluate the effect of *Cajanus cajan* L. species with different planting densities on soil compaction and as specific objectives; measure the compaction of the soil at the beginning and end of the crop cycle, determine the soil moisture percentage as well as the root development of the species at the end of the crop cycle. The data obtained were subjected to analysis of variance (ANOVA) and the means compared through the Tukey test at 5%. Determinations of resistance to soil penetration before the crop establishment and at the end of the crop cycle were not influenced positively; except at 20 cm of density that showed difference at the end of the cycle, the soil moisture percentage was not significant and for root development highly significant differences were found. As regards the soil compaction, it was found that the biological material used with different planting densities had positive effects in the compaction of the soil. Thus, the recommended density is 114,284 plants per hectare.

Key words: Compaction, root development, soil moisture.

INTRODUCTION

Soil compaction is an important feature that affects many aspects of agricultural soils, and is an indicator of the degree of compaction. The compaction limits the root growth and amount of air and water available to the roots (Herrick and Jones, 2002).

The main causes of the degradation of soil structure are related to the climate regime, geomorphological conditions, the intrinsic characteristics of the soils, trampling of animals, and above all the conventional tillage practices, regardless of its being either the wheel forces of the machinery or agricultural implements, especially when the soil is wet or saturated, at which time the soil is more prone to deformation.

Penetrometers are used worldwide to determine the resistance to soil penetration expressed as force per unit area of the cross section of the cone base (Bengough et al., 2001).

The maintenance and recovery of physical

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characteristics can be made feasible by the adoption of soil management practices, especially where a system of crop rotation includes plant species with an aggressive and abundant root system along with high biomass production, contributing to diminish the effects of soil compaction (Cubilla et al., 2002).

The use of green manure helps to protect and recover compacted soil, contributing to the restoration of highly degraded soils through the contribution of organic matter. The species *Cajanus cajan* is one of the alternatives for the most degraded soils because it is a plant with the capacity to adapt to diverse soils and climates, of fast growth and high production power of vegetative material; its root system is deep and reaches up to 3 m, which allows it to survive in conditions of extreme drought. It is a plant with the capacity to fix a high amount of nitrogen in the soil, and root that allows decompaction of soils (Salisbury and Ross, 2012).

The cultivation of this legume offers advantages as soil decompactant. Its roots are deep, act as subsoiler of the soil and can reach up to more than five meters deep, breaking the hard layers (plow foot), which in most small farms are 15 to 20 cm deep (GTZ, 2007).

The general objective was to evaluate the effect of the *C. cajan* species with different densities on soil compaction, and as specific objectives; measure the compaction of the soil at the beginning and end of the crop cycle, determine the percentage of soil moisture as well as root development of the species at the end of the crop cycle.

MATERIALS AND METHODS

The research work was conducted in the town of Huguá Ocampo, 27 km from the city of Concepción, Department of Concepción - Paraguay, circumscribed to the geographic coordinates' 23° 20'35.5'' South latitude and 57° 11' 47.7'' West longitude along with 200 msnm. The climate of the region was classified as frankly humid with an average annual temperature of 12°C and an average annual precipitation of 1000 to 1200 mm. The soil belongs to the large group Alfisol and subgroup Mollic, with panorama in the shape of a sandstone hillock, flat relief of 0 to 3% slope, an approximate height of 200 m above sea level, good drainage and zero rock, plus a climate transition between a Mediterranean type (López et al., 1995).

The sampling for the chemical and physical characterization of soil was conducted before the beginning of the experiment, the results of which were; pH_{water} 6.77; O.M. 0.59%; Al_3meq/100 g soil 0.00; P mg/L 5.76; K cmol/L 0.19; Ca cmol/L 3.07; Mg cmol/L 0.60; S mg/L 7.13; Fe mg/L 74.27; Cu mg/L 2.78; Zn mg/L 3.76; Mn mg/L 181.72; cation exchange capacity cmol/L 6.01; Ca/K 16.19; Ca / Mg 5.12; Mg/K 3.17; and Textures 18% clayey (CETAPAR, 2015).

The experimental design was randomized complete blocks, with four treatments and five replicates. The experimental units were constituted by parcels of 6 × 5 m, constituting 30 m^2 (EU) experimental units. Also, different densities were used in each treatment of pigeonpea (*C. cajan*). The description of the treatments can be seen in Table 1.

Preparation begins with the cleaning and later the delineation of the experimental plot. Before the establishment of culture, the soil penetration resistance was measured using a cone penetrometer (analog) in each subplot and soil samples were taken to measure its moisture.

The *C. cajan* L. sowing was done by manual seeder at different densities after a good rainfall to guarantee the emergence of the seeds. At 30 days after sowing, the weeds were cleaned manually using a hoe.

The determinations of penetration resistance and soil moisture percentage were evaluated before sowing and at the end of the crop cycle at 210 days after sowing; thereafter, root development was measured at the end of the crop cycle.

Resistance to penetration

This was evaluated at depths of (10, 15 and 20 cm) obtaining 15 samples from each EU, with the use of the penetrometer, expressed in Mega pascal (MPa) (Reichert et al., 2003).

Percentage of soil moisture

The soil moisture percentage was measured for one sample per EU, totaling 20 (twenty) soil samples, by a shovel to a depth of 0.20 cm, and were thereafter introduced into containers with 500 g soil each measured by a precision scale and dried in a stove. After 72 h, the samples were weighed on a precision scale and the weight compared with the initial weight, resulting to the percentage of moisture present in the soil of each experimental unit (Reichert et al., 2003).

Root development

The roots of *C. cajan* were measured from the base of the plant neck to the tip of the root. For the measurements and evaluations referring to the distribution of the root system of the crop, the crop profile method described by Böhm (1979) was applied.

Data analysis

The evaluated data were subjected to analysis of variance (ANOVA) and the variables that presented significant statistical differences were compared using the Tukey test at 5% of probability with the statistical program ASSISTAT version 7.7 beta (De Sousa, 2013).

RESULTS AND DISCUSSION

Table 2 shows the results of the obtained means, where the variable of resistance to the penetration of the soil before planting and at the end of the crop cycle does not present a significant difference at the depths evaluated, except at the depth of 20 cm which had a positive effect at the end of the crop cycle.

We can verify that the treatments evaluated with the depth of 10 cm presents lower resistance of soil to the penetration compared with the other depths, whereas as the depth of the soil increases it shows that the soil resistance increases with 15 and 20 cm, to give 4.21 and 4.71 MPa, respectively.

The coefficient of variation before sowing was: at 10 cm, 6.55%; at 15 cm, 7.47%; and at 20 cm, 7.04%, and at the end of the crop cycle reaches 6.83% at 10 cm;

Table 1. Description of the treatments used.

Treatment	Description	Plants per hole	Density (plant ha^{-1})
T1	0.50 between holes cm × 1.00m between rows	3	60.000
T2	0.30 between holes cm × 0.80 m between rows 2 83.333	2	83.333
T3	0.25 between holes cm × 0.70 m between rows 2 114.284	2	114.284
T4	0.20 between holes cm × 0.50 m between rows 2 200,000	2	200.000

Source: Paraguay (2016).

Table 2. Variation of compaction level in the sowing densities of *Cajanus cajan*.

Depth (cm)	Treatment	Penetration resistance (MPa)	
		Before sowing	Crop final cycle
10	T1	3.36[a]	1.73[a]
	T2	3.30[a]	1.68[a]
	T3	3.39[a]	1.69[a]
	T4	3.36[a]	1.73[a]
15	T1	3.91[a]	2.38[a]
	T2	3.80[a]	2.54[a]
	T3	3.92[a]	2.32[a]
	T4	4.21[a]	2.33[a]
20	T1	4.64[a]	2.93[a]
	T2	4.35[a]	3.37[b]
	T3	4.56[a]	3.08[b]
	T4	4.71[a]	2.98[b]

Means followed by the same letter are equal to each other statistically to the Tukey test at 5% probability. MPa: Mega pascal.
Source: Paraguay (2016).

7.29% at 15 cm; and 4.97% at 20 cm, which are considered good or very good being that it is below 15% of the CV in which it is existing as a statistical parameter that indicates, in percentage terms, the dispersion of a series of data with respect to the mean value. According to Pimentel and García (2002), the value of the CV is equal to 0 when there are no differences between the points, resulting in a totally homogeneous distribution. In synthesis, this parameter gives us an idea of the precision of the experiment. Considering the CVs commonly obtained in field agricultural trials, we can consider them good or very good when less than 15%, acceptable when between 15 to 25%, and bad to discard when they are greater than 25%.

With the results obtained in this study, a level of differential soil resistance was found, in which the greater soil depth showed the highest values, related to the compaction than the values found at 10 and 15 cm.

According to Nacci and Pla (1992), the highest values of resistance to penetration take place between 15 and 25 cm deep, which reaffirms the physical restrictions of the soil for the growth and development of the roots attributed to the effect of conventional management. The same trend is reflected in this study, where the same behavior is noted, and from 15 to 20 cm is the highest level of compaction.

Nesmith et al. (1987) estimated that the critical levels of resistance to plant growth vary according to the type of soil and the cultivated species. The authors indicate that the values 1, 2 and 3.5 MPa, respectively, are the critical thresholds of resistance to root penetration. In general, however, Taylor et al. (1966) expressed that the critical limit value is 2MPa, with these authors showing that the level of compaction of the soil studied is compacted.

Krüger (1996), who observed soils with several years of tillage in Argentina, revealed that after 15 cm of the surface a compacted layer appears, which hinders the radical development of the plants.

Results of the obtained means, where the comparison of the different treatments is made with respect to the variable of resistance to the penetration of the soil measured at the end of the crop cycle (Table 2), confirms that among the evaluated treatments with the depth of 10 and 15 cm, there was no significant effects; however, compared to the data (Table 2), reduction of the level of soil resistance with use of different densities of the

Table 3. Variation in soil moisture content (%) in sowing densities of *Cajanus cajan*. Concepción, Paraguay, 2016.

Treatment	% of soil moisture content	
	Before sowing	Crop final cycle
T1	5.20[a]	8.81[a]
T2	5.40[a]	9.80[a]
T3	4.85[a]	9.15[a]
T4	4.00[a]	8.80[a]
CV %	23.80	46.87
G.M.	4.86	9.14

Means followed by the same letter are equal to each other statistically by the Tukey test at 5%. CV: Coefficient of variation; GM: general means.

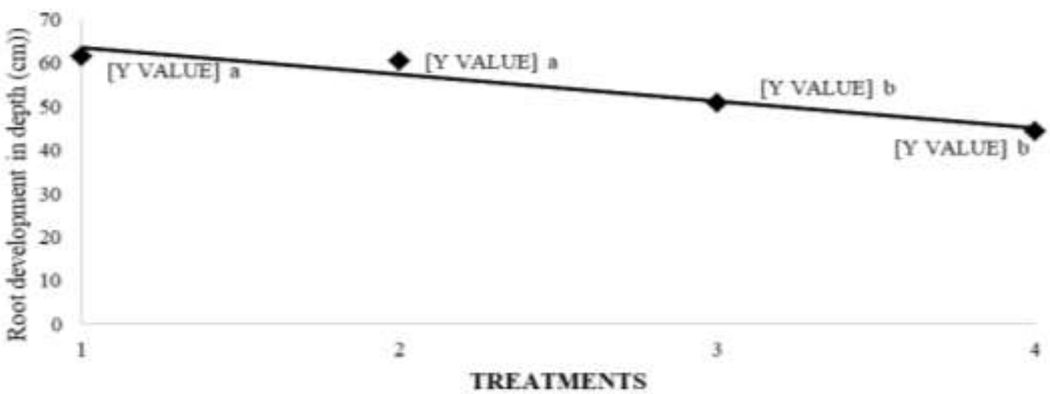

Figure 1. Root development in soil depth according to the densities of *Cajanus cajan*. C.V. = 7.26%. Source: Paraguay (2016).

biological material (*C. cajan*) is considerably noticeable. The T2 at 10 cm has a difference of 1.68 MPa, whereas at a depth of 20 cm, there are significant differences; the lower soil resistance shows T1, being T2, T3 and T4 similar to each other, demonstrating the positive effect of the use of *C. cajan* in the compaction of the soil.

Forsythe et al. (2005) determined that the critical value of penetration resistance for maize crop yield is 2.75 MPa. The same author also reports the value of 2.96 MPa as a limiting value for the growth of the roots. In this work, it was possible to obtain 2.93 MPa at 20 cm depth, which agrees with the mentioned authors, thus implying that the biological material used corrected to a great extent the initial compaction of the soil of the plot studied.

Soil moisture percentage

Contrasting the data obtained in the determination of soil moisture percentage carried out together with the determination of resistance to soil penetration, the average of 4.85% soil moisture was found. At the end of the crop cycle, it can be noticed that the moisture of the soil amounted to 9.15%, observing the effect of the coverage of the fallen leaves of *C. cajan* (Table 3).

Soil moisture, as well as soil depth, has direct and indirect influence on the results in terms of resistance to penetration in the different management systems (Orzuza, 2010).

Soil compaction is directly related to the moisture and depth of the soil as can be seen in the results obtained, where the higher the percentage of moisture present in the soil, the greater will be its depth leading to decrease in compaction (Myers and Robbins, 1991).

Guillén et al. (2006) found lower values of resistance to penetration even in the months of lower precipitation with average values of 2 MPa. In this research, the percentage of moisture found agrees with the authors', since in all the depths, the indicated average were significantly exceeded, implying the direct relationship of soil moisture with soil compaction.

Root development

Analysis of Figure 1 revealed that T4 had less depth in the development of the roots compared with the other treatments whereas T1 presented the best value with

61.56 cm. This implies that there is a close relationship with the soil moisture mentioned earlier.

The root distribution for the density of 200,000 pl ha^{-1} (T4) was the one with the lowest value, and with T1 being the best, the development of the roots reached an average of 61.56 cm in depth, being thicker, deeper and where better effect was obtained in the compaction of the soil, far surpassing the other treatments mentioned in Figure 1.

Spek and Purnomosidhi (1995) mentioned that the competition for water and nutrients depends on the relative distribution of the fine roots of the plants; however, it must be taken into account that this competition occurs with the vegetation that is in its base and has to do with the diameter and depth of these roots. During determination of this effect, it can be noticed that when increasing the plant density of the crop, development of the roots diminished remarkably due to the competition for nutrients.

Rojas (2000) found no significant differences in soil moisture content. In addition, the distribution of roots varied significantly between the different depths, which coincide with what was found in this study.

CONCLUSIONS AND RECOMMENDATIONS

The different densities used in the present experiment revealed positive results in resistance of the soil to penetration in the three depths, which could penetrate and break the surface with the soil moisture percentage becoming better with high density (200,000 pl ha^{-1}) while in depth root development has been found to influence the low density (60,000 pl ha^{-1}).

The initial compaction of the soil is at a high level in the three depths that were measured; at 10 cm the level found was 3.63 Mpa, at 15 cm it was 4.21 Mpa, while for 20 cm the level was 4.71 Mpa with everyone above the critical level (2 Mpa).

The compaction at the end of the crop cycle in the three determinations made shows that the biological material used (*C. cajan)*, had positive effects since it could penetrate and break the surface, solving the problem of the initial compaction mentioned. Here, for the 10 cm depth, the level found was 1.68 MPa, at 15 cm it was 3.32 MPa whereas at 20 cm the level was 2.93 MPa.

The soil moisture percentage had an average of 4.85% at the beginning of the implementation of the crop and with 9.15% at the end of the crop.

The greatest depth of the root was found in the case of T1 with 61.56 cm, greatly surpassing the surface of the plowing foot.

It is also recommended that the research be continued to obtain reliable results so that the producers, when accessing the information, can obtain relevant data to select the suitable practices when faced with a considerable degraded and compacted soil and thus proceed to its adequate recovery.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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