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INFLUÊNCIA DA ADUBAÇÃO VERDE NA INFILTRAÇÃO DE ÁGUA E NA RESISTÊNCIA A PENETRAÇÃO DO SOLO SOB CULTIVO ROTACIONADO COM CANA-DE-AÇÚCAR E SORGO SACARINO

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1 RESUMO

As características hidráulicas do solo possuem papel de grande relevância no desenvolvimento das plantas pois atuam no armazenamento e transporte de água. O presente estudo teve como objetivo utilizar adubos verdes na reforma do canavial, avaliando a influência do cultivo da crotalária e do feijão guandu em rotação com o sorgo sacarino e cana-de-açúcar na infiltração de água e na resistência à penetração do solo. As equações de infiltração, seguindo o modelo de Kostiakov, foram determinadas a partir dos dados resultantes do teste com infiltrômetro de anel concêntrico, realizado após o primeiro corte da cana, em uma área experimental na cidade de Cabrália Paulista, SP, Brasil, já a resistência a penetração foi mensurada usando o penetrômeto. As rotações com adubos verdes propiciaram aumento da velocidade de infiltração básica (VIB) e redução da resistência à penetração. A crotalária destacou-se em todas as variáveis estudadas, resultando em um aumento estatisticamente significativo de 200% na VIB do solo e uma redução significativa de 15% na resistência a penetração. O feijão guandu também promoveu melhoras nas condições do solo, entretanto essas foram menos expressivas. Desta forma, pode-se afirmar que o uso da crotalária e do feijão guandu resultam na melhoria das características físicas do solo.

Palavras-chave: *Crotalária ochroleuca*, velocidade de infiltração básica, Kostiakov, rotação de culturas, *Sorghum bicolor L. Moench*, *Saccharum officinarum.*

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INFLUENCE OF GREEN MANURE ON WATER INFILTRATION AND RESISTANCE TO SOIL PENETRATION UNDER ROTATIONAL CULTURE WITH SUGARCANE AND SWEET SORGHUM

2 ABSTRACT

The hydraulic characteristics of the soil play a very important role in the development of plants, as they act in the storage and transport of water. The objective of the present study was to use green manures in sugarcane plantation reform, evaluating the effects of crotalaria and guandu bean in rotation with sweet sorghum and sugarcane on water infiltration and resistance to soil penetration. The infiltration equations, following the Kostiakov model, were determined from the data resulting from the test with a concentric ring infiltrometer, carried out after the first sugarcane cut, in an experimental area in the city of Cabrália Paulista, SP, Brazil, penetration resistance was measured using the penetrometer. The rotations with green manures provided an increase in the basic infiltration velocity (BIV) and a reduction in penetration resistance. Crotalaria stood out in all studied variables, resulting in a statistically significant increase of 200% in soil BIV and a significant reduction of 15% in penetration resistance. Guandu bean also promoted improvements in soil conditions, however these were less expressive. In this way, it can be stated that the use of crotalaria and guandu bean results in the improvement of the physical characteristics of the soil.

Keywords: *Crotalária ochraleuca*, basic infiltration rate, kostiakov, crop rotation, *Sorghum bicolor L. Moench, Saccharum officinarum.*

3 INTRODUCTION

Water is essential for living beings and has several functions, such as nutrient transport, temperature buffering, solvent, etc. (AUNG; JIANG; HE, 2017). Plants essentially need soil to supply water and nutrients; thus, to maintain effective development, maintaining the quality and reserves of water accessible to the roots is necessary (EHLERS; GOSS, 2016).

Infiltration, which is considered the process of water entry into the soil, is one of the central points for promoting water accessibility to plants. Furthermore, it can help control surface runoff and erosion (LOURENCETTI; GOMES; BRANCO, 2020). The infiltration rate is highly relevant in the planning of irrigation systems and directly affects process performance and water use efficiency, as it affects the dynamics of water in the soil (EBRAHIMIAN et al., 2020; SILVA et al., 2017).

The basic infiltration rate (BIR) is an extremely important factor in the size of irrigation projects and can be determined via several methods, among which the concentric ring method stands out (WICKRAMAARACHCHI; VENUKANAN; DILUCKSHANARAJ, 2018). The concentric ring method consists of a ring inserted in the soil that receives a hydraulic load, and the infiltration rate is measured over time until it becomes constant (NETTO et al., 2013).

Sugarcane is highly important to the Brazilian economy, being, among other things, a raw material for the production of sugar, ethanol, and electricity. It is considered an extractive crop, with 90.8% of harvests being carried out mechanically (SUGAR CANE, 2023), with high machinery traffic, resulting in physical changes to the soil. Thus, it can alter soil compaction, which decreases soil porosity and increases its apparent density, implying a reduction in water infiltration into the soil (CHEN; WEIL, HILL, 2014; MOSSADEGHI-BJ ÖRKLUND et al., 2019; WANG et al., 2015).

One of the most widely used indicators to assess soil physical conditions is penetration resistance (PR). This method can determine the degree of compaction, which describes the physical resistance exerted by the soil on the roots and is highly correlated with plant development (LABEGALINI et al., 2016; OLIVEIRA FILHO et al., 2015). It can be a great ally in analyzing the effects of adopted management systems (VALADÃO et al., 2015). PR is highly dependent on soil texture, structure, and mineralogy, and its increase is a result of the intense use of agricultural machinery and implements (LIMA; LÉON; SILVA, 2013).

Owing to the need to increase productivity and because sugarcane cultivation has a period of inactivity called sugarcane reform, some crops can be associated with it, such as sweet sorghum (*Sorghum bicolor L. Moench*) (GOMES; BAJAY, 2017; MAY et al., 2013).

Sweet sorghum is one of the raw materials for the production of ethanol through the fermentation of sugars present in its stalks, presenting wide adaptability to different climate and soil conditions, being indicated as an alternative for shortening the off-season, thus increasing productivity in liters of ethanol per hectare (EMYDIO, 2010).

Green manuring involves incorporating plants into the soil to improve its properties and promote nutrient recycling more sustainably. Crops that can be used include sunn hemp and pigeon pea, two legumes with the important characteristic of having deep, well-developed roots that create porous channels in the soil, aiding in decompaction and increasing infiltration (P ACHECO et al., 2015).

Owing to the great importance of water for plant development and the scarcity of studies related to the increase in water infiltration into the soil through the use of green manures, this study aimed to use Crotalaria and pigeon pea in the reform of sugarcane fields and to analyze their ability to alter the speed of water infiltration into the soil and their resistance to soil penetration.

4 MATERIALS AND METHODS

The experiment was carried out in the experimental area of the “Astor de Mattos Carvalho” Technical School, located in the municipality of Cabrália Paulista, SP, Brazil, at an altitude of 600 m, latitude of 22°28'47.0” S and longitude of 49°19'08.1” W. The soil in the area is classified according to the SIBCS as Dystrophic Yellow Latosol, and the climate classification of the site is Cwa according to the Köppen classification: humid temperate climate with dry winters and hot summers and a productive environment for sugarcane “D”: with medium/low production potential. The area used for the study had a history of sugarcane cultivation for six years.

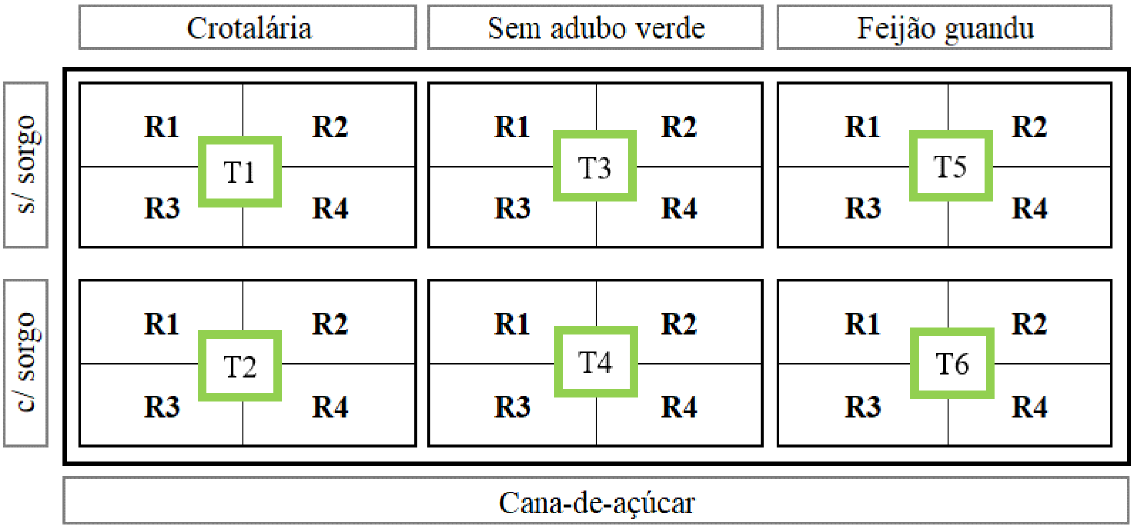
In the spring, sunn hemp (*Crotalaria ochraleuca)* and pigeon pea (*Cajanus cajan*) broadcast at a seed rate of 20 kg ha -1. The green manure was harvested 120 days after sowing (DAS). Subsequently, Nexsteppe® Malibu 1001 hybrid sweet sorghum was sown with a simple row spacing of 0.5 m and 6 to 7 seeds per linear meter, aiming to obtain a final stand of 120,000 plants ha $^{-1}$. Harvesting was carried out manually in early autumn 110 days after sowing (DAS). The sugarcane cultivar RB 867515 was planted in the spring of the second year of the experiment after conventional soil preparation.

The experimental design used was that of subdivided plots, with different rotation situations (treatments):

- T1: sugarcane planted over Crotalaria;
- T2: sugarcane planted on sweet sorghum in rotation with Crotalaria;
- T3: sugarcane;
- T4: sugarcane planted on sweet sorghum;
- T5: sugarcane planted over pigeon pea;
- T6: sugarcane planted on sweet sorghum in rotation with pigeon pea.

Four replicates were adopted for each treatment in a 3x2 factorial scheme, with factor A: three rotation situations: with crotalaria, without green manure and with pigeon pea; and factor B: two situations: without sweet sorghum and with sweet sorghum, as illustrated in Figure 1.

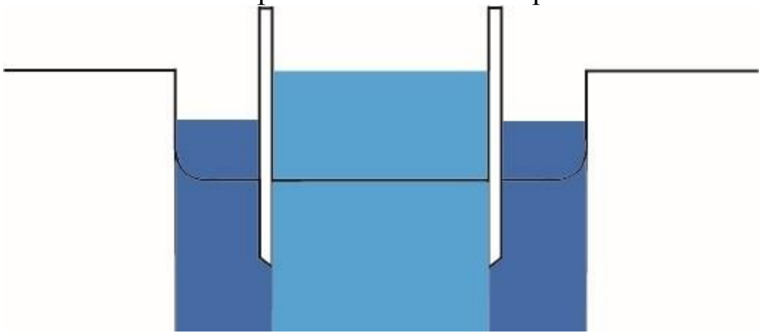
Figure 1 Experimental delimitation



Source: The authors.

Infiltration was determined after the first sugarcane cut, with the unsaturated soil, via a ring infiltrometer via a methodology adapted from Brandão et al. (2012). Unlike the aforementioned author, a flat pit measuring approximately 50 cm in diameter and 10 cm in height was created, and a ring measuring 30 cm in height and 24.2 cm in internal diameter was used. A pit was created to prevent lateral infiltration of fluid from within the ring (Figure 2). The cylinders were inserted at a depth of 10 cm, and the water depth in the ring was maintained at a height that varied between 8 and 10 cm.

Figure 2. Section of the front view representation in the experiment with a ring infiltrometer



Source: The authors.

The water in the ring was replaced whenever the water depth reached its minimum limit (8 cm). Readings of the infiltrated depth were taken at 5-minute intervals for the first thirty minutes of the test, then at 10-minute intervals for the next hour, and finally at 15-minute intervals until constant values were reached over time, and a total test time of at least 2.5 hours was completed.

The basic infiltration rate was subsequently determined from the test data, and the infiltration equation was generated according to the Kostiakov model (FOK, 1986):

$$I = k * t^{n} \quad (1)$$

where "I" is the accumulated infiltration; "t" is the test time; and "k" and "n" are parameters related to the soil type. In addition, the infiltration rate equation (eq. 2) was determined for each treatment.

$$VI = n * k * t^{n-1} \quad (2)$$

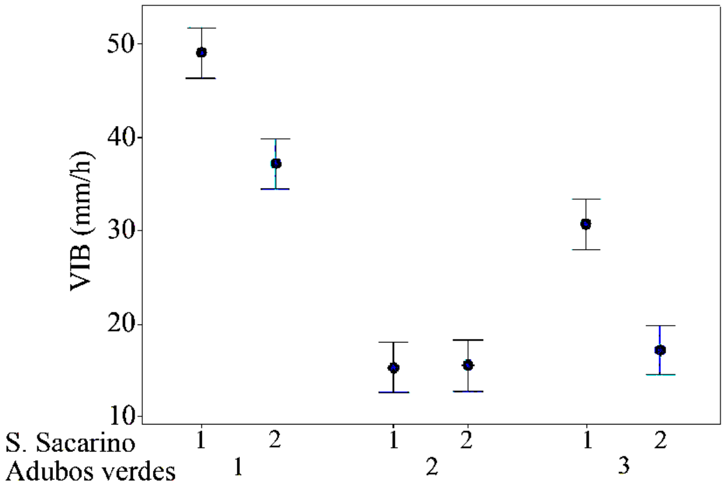
To determine the mechanical resistance to penetration, a penetrometer was used. Falker®, Penetrolog PLG 1020 model with a 20.27 mm diameter tip and a 323 mm2 projection area. The instrument measures the pressure (kPa) required to insert the tip into the soil and relates it to the profile depth via a distance sensor (ultrasound) that measures the distance between the device and a metal plate placed in the soil. Six replicates were performed at the end of the sugarcane cycle in each of the twenty-four plots, totaling 144 readings.

The results were subjected to statistical analysis via Tukey's test at the 5% probability level to determine whether the differences between the results could be considered statistically significant. Analysis of variance (F test) was also applied, both with Minitab® software.

5 RESULTS AND DISCUSSION

The data presented in Figure 3 and Table 1 indicate that the interaction between the proposed crop rotations significantly influenced the basic infiltration rate (VIB) values. The sunn hemp without sweet sorghum combination resulted in the highest VIB rate (49.10 mm h^{-1}), followed by the sunn hemp with sweet sorghum combination (37.19 mm h^{-1}) and the pigeon pea without sweet sorghum (30.69 mm h^{-1}). Finally, the combinations without green manures—without sweet sorghum—and without green manures—with sweet sorghum and pigeon pea—with sweet sorghum presented values of 15.30, 15.48 and 17.17 mm h^{-1}, respectively.

Figure 3. Average basic infiltration rate (BIR) with respective confidence intervals for combinations of green manure and sweet sorghum



Green manures: 1- crotalaria; 2- without green manure; 3- pigeon pea. Sweet sorghum: 1- without sweet sorghum; 2- with sweet sorghum

Source: The authors.

Table 1BIR values in soils cultivated with sugarcane under different rotation conditions

Treatment	Green Manure Levels	Sweet Sorghum Levels	VIB (mm h $^{-1}$)
T1	Crotalaria	No sweet sorghum	49.10 A
T2	Crotalaria	With sweet sorghum	37.19 B
T3	No green manures	No sweet sorghum	15:30 D
T4	No green manures	With sweet sorghum	15.48 D
T5	Pigeon pea	No sweet sorghum	30.69 C
T6	Pigeon pea	With sweet sorghum	17.17 D
	F Test (Interaction)		16.69**
	CV %		9.81

Different letters indicate significant differences according to Tukey's test (5%). **significant at the 1% probability level. CV – Coefficient of variation.

Source: The authors.

The rotation with sunn hemp without sweet sorghum (T1) resulted in the highest VIB rates (Table 1), with the VIB rates in this treatment being 220% higher than those in the treatment where only sugarcane was cultivated (T3). The influence of sweet sorghum was also noted, with VIB decreasing in some cases (T1 compared with T2 and T5 compared with T6). In the treatments where there was no rotation with green manures, the presence of sweet sorghum did not significantly differ.

The infiltration rate is affected by a variety of factors, such as bulk density, soil composition, and cover cropping. A study by Pereira et al. (2019) in vegetative regeneration areas reported VIB values ranging from 29.6 cm h-- ^{1} to 47.8 cm h $^{-1}$, demonstrating that the clay percentage and soil density significantly influence water infiltration parameters. In terms of the improvement in VIB rates due to the use of cover crops, Viana et al. (2015) reported values of 36.3 cm h $^{-1}$ and 23.4 cm h $^{-1}$ for soils with no-tillage and conventional tillage systems, respectively.

The positive impact of green manure is a result of its ability to improve soil physical, chemical, and biological properties, such as density, structure, nitrogen fixation, moisture retention, and organic matter content. Sunn hemp, with its deep and well-developed roots, primarily improves the soil structure, reduces penetration resistance, increases the infiltration rate and soil water storage capacity, and protects against erosion (DAS et al., 2020; MARSHALL et al., 2016; ZACCHEO et al., 2016).

Sunn hemp was not only responsible for the highest rates of VIB (Figure 3) but also provided high rates even in rotation with sweet sorghum, a crop that receives several cultural treatments (sowing, fertilization, application of pesticides, among others), generating a greater flow of traffic in the area, which could cause physical changes to the soil (CHEN; WEIL, HILL, 2014; WANG et al., 2015). In contrast, treatment with pigeon pea was not significantly different from treatment with sweet sorghum. Santos et al. (2016) also reported good results with the cultivation of Crotalaria as a cover crop for sweet corn, obtaining a VIB of 123 mm h $^{-1}$, which is considered very high.

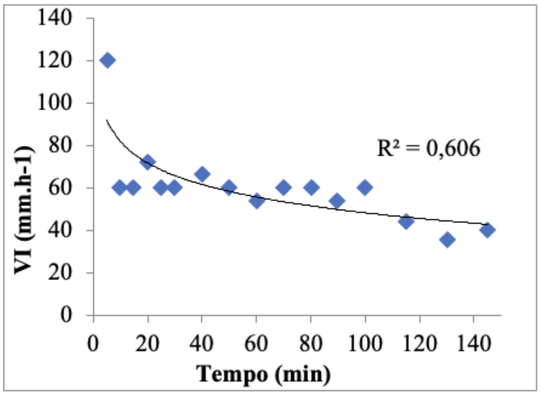
High or very high infiltration rates reduce the possibility of surface runoff and, consequently, water erosion. They can also increase water storage capacities when associated with layers that retain this moisture. However, they can lead to the leaching of nitrates and other ions (COSTA et al., 2018).

However, it is necessary to consider that, despite being consistent with other forms of evaluation, the method used overestimates the VIB values, which can be explained by the presence of the water load throughout the test (SANTI et al., 2012; ZWIRTES et al., 2013). However, for the objectives proposed in this research, the VIB value is used to classify which of the treatments has the highest speed compared to the others, thus inferring the benefits of rotations with green manures.

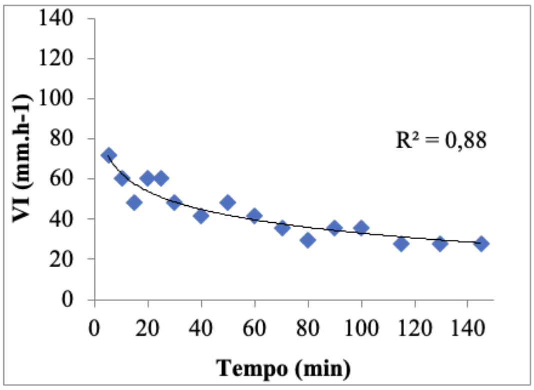
Figure 4 presents the infiltration rate, infiltration equation, and infiltration rate equation data found throughout the experiment. In all the treatments, the initial water movement occurred more easily and quickly under the gravitational effect and unsaturated soil conditions. Oliveira, Silva and Melo (2020) reported that sandy soils also have a smaller contact surface area, lower initial retention, and consequently greater ease in redistributing water within the soil layers.

Notably, the infiltration process occurs slowly, always starting at a very high rate that decreases over time and becomes constant. The decrease in rate is also due to the action of the gravitational pressure gradient, which decreases over time and becomes stable, also stabilizing the infiltration rate, approaching hydraulic conductivity (Shahidian et al., 2017). This condition is very important because when the soil is saturated, it is not possible to maintain an infiltration rate greater than or equal to the rainfall intensity (irrigation), thus exceeding hydraulic conductivity and consequently generating surface runoff (Wang et al*.*). , 2015). There was a faster decrease in the infiltration rate over time in the treatments without the green manure rotation (Figures 4C and 4D), and the infiltration rate was greater than that in the previous two situations for the treatments in rotation with pigeon pea.

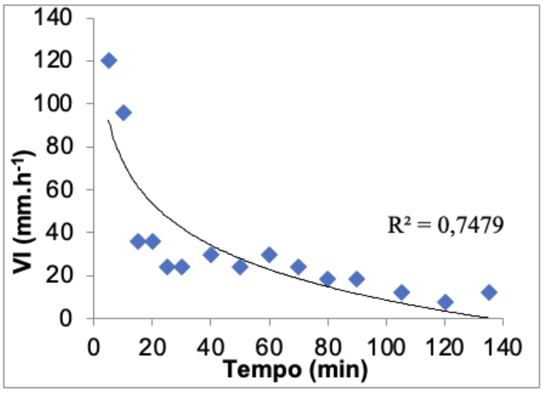
Figure 4. Infiltration rate (I) in soils cultivated with sugarcane under different rotation conditions



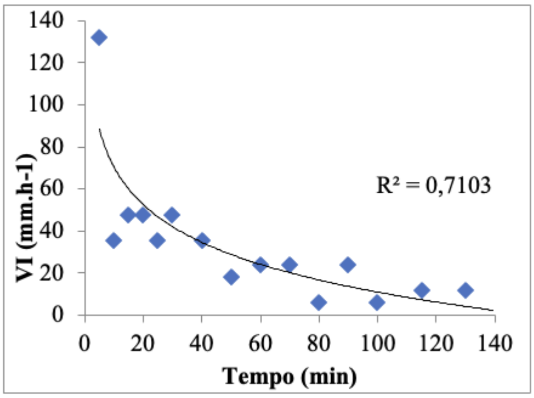
I=2,36132t^0,8148
VI=1,92404t^-0,185
(a) Tratamento 1



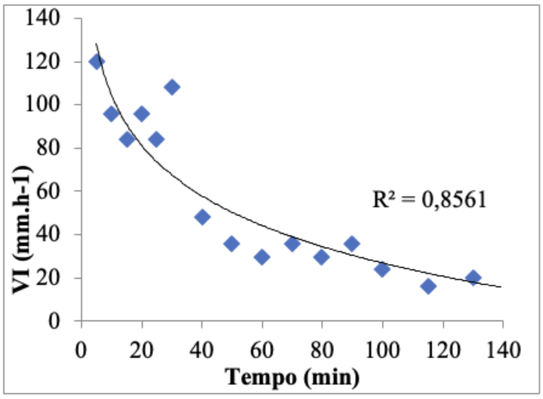
I=2t^0,8226
VI=1t^-0,177
(b) Tratamento 2



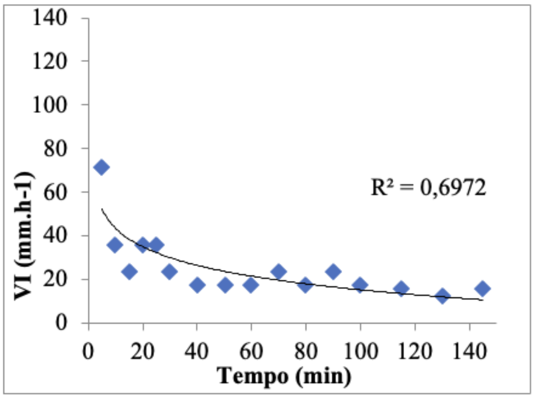
I=4,88523t^0,5211
VI=2,54577t^-0,479
(c) Tratamento 3



I=4,4649t^0,537
VI=2,396t^-0,46
(d) Tratamento 4



I=4,0902t^0,676
VI=2,76376t^-0,324
(e) Tratamento 5



I=1,978463t^0,657889
VI=1,301609t^-0,34211
(f) Tratamento 6

T1: sugarcane planted on sunn hemp; T2: sugarcane planted on sweet sorghum in rotation with sunn hemp; T3: sugarcane; T4: sugarcane planted on sweet sorghum; T5: sugarcane planted on pigeon pea; T6: sugarcane planted on sweet sorghum in rotation with pigeon pea.
Source: The authors.

With respect to the penetration resistance (PR) test, Table 2 shows significant differences between the pressures required to penetrate the soil in plots with green manures (sunn hemp and pigeon pea) and those required without, indicating that these green manures have the ability to improve the physical structure of the soil. Some studies indicate that when associated with other strategies, such as mechanical scarification, the implementation of green manures can become more efficient (POTT et al., 2019; SILVEIRA JUNIOR et al., 2012).

Table 2. Average values obtained for penetration pressure and depth of maximum pressure in plots planted with sugarcane in different rotation situations, Cabrália Paulista – SP, 2017 Harvest

Green Manures (A)	Pressure (kPa)	Max. pressure depth (cm)
Crotalaria	3742.24 B	40.21 A
No green manures	4318.71 A	36.00 B
Pigeon pea	3889.25 B	38.58 AB
DMS	385.26	3.22
F Test	13.71**	4.87**
Sweet Sorghum (B)		
With	4040.32 A	38.36 A
Without	4020.63 A	38.16 A
DMS	308.36	2.20
F Test	0.02 ns	0.03 ns
CV%	23.17	17.41
Inter AxB	0.04 ns	2.60 ns

Different letters indicate significant differences according to Tukey's test (5%). **significant at the 1% probability level. LSD – least significant deviation. CV – Coefficient of variation
Source: The authors.

In terms of the depth of maximum pressure, the plots with green manures presented greater depth values than did the plots without green manures (Table 2). The effective depth of a plant's root system is the depth where 80% of its root system is located (BERNARDO; SOARES; MANTOVANI, 2008). Souza et al. (2013) reported the effective depth for the sugarcane cultivar SP-903414 in the first 40 cm for the nonirrigated treatment (rainfed) in Piracicaba, SP. Thus, the rotation with green manures and, in this study, mainly with Crotalaria, can provide a range of slightly compacted soil that includes the range of the effective depth of the root system of the sugarcane crop, as evidenced by the lower pressure values and the greater depth of maximum pressure . There were no significant differences due to the use of sweet sorghum or the interaction between the green manure and sweet sorghum factors.

The implanted green manures have deep roots with many branches and capillaries, reducing penetration resistance, increasing VIB, and, consequently, improving the hydraulic condition of water incorporation into the soil. Pacheco et al. (2015) highlighted the high root volume and large amount of dry matter in Crotalaria roots, indicating the potential to improve the physical characteristics of the soil, such as increasing porosity and improving its hydraulic capacity.

6 CONCLUSIONS

Crop rotation with green manures can significantly improve soil hydraulic characteristics. Sunn hemp, in particular, presented high VIB rates, low penetration resistance, and greater depths of maximum penetration pressure, indicating that this crop may be a promising strategy for improving soil hydraulic characteristics. These results are consistent with those of previous studies demonstrating the ability of green manures to improve the physical, chemical, and biological properties of soil.

Continuing studies in this area is essential to improve the understanding of the interactions between crop rotations and soil quality, with the aim of developing more efficient agricultural practices.

7 THANKS

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