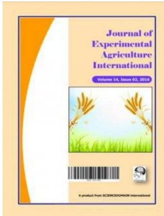

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Soil Mechanical Resistance Penetration after Fifteen Years with Previous Crops and Tillage Systems and Productivity of Green Corn Cob in Northeast Brazil

Alceu Pedrotti[1], Renisson Neponuceno de Araújo Filho[2*], Sara Julliane Ribeiro Assunção[1], Raimundo Rodrigues Gomes Filho[1], Fernanda Cristina Caparelli de Oliveira[1], Francisco Sandro Rodrigues Holanda[1], Victor Casimiro Piscoya[3], and Moacyr Cunha Filho[3]

[1]Universidade Federal de Sergipe, Av. Marechal Rondon, s/n, CEP 49100-000, Jardim Rosa Elze, São Cristóvão - SE, Brazil.
[2]Universidade Federal do Tocantins, Rua Badejós, Lote 7, Chácaras 69/72, s/n - Zona Rural, CEP 77402-970, Gurupi, TO, Brazil.
[3]Universidade Federal Rural de Pernambuco, Rua Dom Manoel de Medeiros, s/n, Dois Irmãos, CEP 52171-900, Recife, PE, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Author SJRA conducted the study, collected the analyzes in the field and did the statistical analysis of the data, wrote the protocol and wrote the first draft of the manuscript. Authors AP, RNAF and RRGF designed the study and monitored and supervised all of this study. Author FSRH, VCP and MCF assisted in literature searches, writing in the manuscript and discussing the data. Authors FSRH, RNAF and AP helped in the search of the literature and in the translation of the same into English language. All authors read and approved the final manuscript.

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ABSTRACT

Conservation systems for less soil movement and when associated with previous crops may reduce the effects of soil compaction. The objective of this work was to evaluate soil mechanical resistance penetration (MRP) in different cropping systems associated with previous corn crop after fifteen

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**Corresponding author: E-mail: alceupedrotti@gmail.com;*

years. The experimental design was composed of experimental strips with subdivided plots, combining three soils management systems: CC- conventional cultivation, MC- minimum cultivation and NT- no-tillage, and four species of crops antecedent to maize for the production of commercial ears of green corn. In the determination of soil MRP, the electronic penetrometer (FALKER model SoloTrack PLG 5200) was used, with readings up to a depth of 400 mm. The results showed that there was a significant effect on the MRP values of the soil when submitted to the different cropping systems and previous crops at the end of fifteen years. The lowest MRP values were located in the superficial layers in the CC and MC. The NT cultivar system showed higher MRP values, at depth 0-100 mm. At conditions of tableland, after fifteen years, it was observed that the NT system provides better corn productivity levels combined with lower MRP values along the profile.

Keywords: Soil management; conservation systems; soil compaction.

1. INTRODUCTION

Maize (*Zea mays* L.) in Brazil and in the world is considered one of the most important grains, both economically and socially, as it is used in human and animal feeding [1]. Maize occupies a prominent place among cereals and there is no other cereal that has such immense potential [2]. In terms of world-wide area, Brazil stands next to the USA, India, China and Mexico, while it ranks second to the US when it relates to production [3].

In the northeastern Brazil state of Sergipe occupies the fourth position as the largest producer of corn to produce 495,729 tonnes and the sixteenth placed in Brazil [4]. The Northeastern region presented an average productivity below the national average, with approximately 1,600 kg ha^{-1}, but Sergipe production is higher with more than 4 thousand kg ha^{-1}, placing the state in the position of largest producer in the region [5].

The use of conservationist systems of soil management associated with previous crops (soil cover plants) to commercial crops may contribute to higher productivity [6]. Thus, in the conditions practiced by tropical agriculture, it can be considered that soil management aiming at reducing compaction, as a viable alternative, resulting from the absence of soil rotation and increased biological activity [7].

The search for management methods and technologies that contribute to the sustainability of agroecosystems is of paramount importance to improve soil quality [8]. This contribution can be made through the indication of cropping systems associated to the effects of the soil cover plants, evaluated by physical factors that are directly related to the development of the plants, and consequently the crop productivity [9], a primordial aspect in the edaphoclimatic conditions of tropical regions. Thus, the different soil management systems, associated to different antecedent crops, provoke alterations in MRP and consequently interfere in the maize productivity parameters. The present study had as objective to evaluate MRP in different cropping systems and succession cultures to green corn after fifteen years of management.

2. MATERIALS AND METHODS

The present study was developed at the fifteenth year of conduction in an experiment implemented in 2001 at the Campus Rural Experimental Station of the Universidade Federal of Sergipe, in the municipality of São Cristóvão, state of Sergipe, northeastern Brazil, with geographic coordinates 10°19'S and 36°39 'W and 22 meters of average altitude in relation to sea level. The region has a climate, according to the Köppen classification, type As', tropical rainy with dry summer and rainfall around 1200 mm annually, with rainfall concentrated in the months of april to september [10]. The soil was classified as Ultisols, with textural B horizon, A moderate sandy loam, derived from sediments of the Barreiras group [11].

The horizons present in the soil profile are: A (0 - 27 cm) and Bt (28 - 77 cm), with sandy texture (sand: 82 g kg^{-1}, silt: 13 g kg^{-1} and clay: 5 g kg^{-1}) and clay loam (sand: 15 g kg^{-1}, silt: 25 g kg^{-1} and clay: 60 g kg^{-1}), respectively. The soil bulk density values, obtained by the volumetric ring method, respectively for the soil layers 0-10 and 10-20 cm were 1.42 and 1.44 g cm^{-3} in the CC, 1.50 and 1.53 g cm^{-3} in CM and 1.44 and 1.56 g cm^{-3} in PD. In this way it can be observed that, in average values, there is a directly proportional behavior of these values with the behavior obtained in the RMP evaluation.

The management systems implemented were conventional cultivation (CC), minimum cultivation (MC) and no-tillage (NT). Previously to each annual corn planting cycle, the experimental plots were cultivated: sunn hemp (*Crotalaria juncea* L.) and pigeon pea (*Cajanus cajan* (L.) Huth) until the 2008 harvest, millet (*Pennisetum glaucum (L.)R. Brown*) and sunflower (*Helianthus annuus*). The first two plants were commercial, and the last two were used as soil cover plants.

The experimental plots presented a 6 x 10 m area, with a space of 1 m between the plots and, following the irrigation system implanted in the experimental area. In this way, 3x4 factorial was obtained, being three soils management systems, and four succession succession cultures, with three replications, totaling 36 experimental plots.

Biomatrix variety BM 3061 was sown annually, with a spacing of five plants per linear meter and 0.80 m between rows, constituting twelve rows per plot. For sowing, a manual fertilizer planter was used to make basic fertilization. The nutrients applied at the time of sowing consisted of nitrogen in the form of urea (45% of N), phosphorus in the form of triple superphosphate (42% of P_2O_5) and potassium in the form of potassium chloride (58% of K_2O), corresponding at 120, 90 and 110 kg ha^{-1}, respectively, with N applied 50% at sowing and 50% at 30 days after seedling germination. These values were obtained based on the soil analysis and recommendations established for the corn crop, according to [12]. The liming, for the correction of soil acidity and calcium and magnesium supply was carried out according to the chemical analysis of the soil, following the technical recommendations, for the corn crop in the state of Sergipe [12], on average every four years.

In the soil preparation, a disk plow and leveling grid was used for the CC preparation, closed light leveling grid for the MC and no NT preparation equipment, and weeds controlled in this system by manual weeding associated with the use of herbicides: Gliphosate, Atrazine and Nicosulfuron according to the need and stage of the crop cycle. For CC and MC systems, weed control during the cycle of the different crops studied in the experimental plots, when necessary, manual weeding through hoes associated with the herbicides Atrazine and Nicosulfuron was used. At the time of harvest to evaluate the productivity of green corn in different plots, the number of plants, weight and number of ears of commercial value were counted.

The MRP evaluation was based on the automated penetrometer - FALKER, model SoloTrack PLG 5200, capable of electronic data acquisition. The penetrometer moved at a rate of 4 cm per second, its rod / probe being 40 cm long, cone angle of the end of the stem tip 30°, diameter of the metal rod 0.95 cm, conical tip of approximately 0.8 cm^2 section. Eight random points were sampled in each of the three replicates, distributed in the plots in a diagonal line, and later a plot was drawn relating the depth in mm and applied force for soil penetration in KPa. The representative graph of MRP was obtained through the PenetroLOG Software [13]. The data concerning the penetrometer were extracted and analyzed to the depth of 400 mm in the soil profile. In each plot, moisture was quantified through the collection of three simple soil samples at depth of 0-200 mm and 200-400 mm, using the gravimetric method according to the methodology described in [14].

The data obtained with MRP, moisture, corn yield and plant numbers per plot were submitted to analysis of variance and, when significant, the means were compared by means of the Tukey test at the 5% level of significance. Statistical analyzes were performed using the statistical program Sisvar [15].

3. RESULTS AND DISCUSSION

The average values for each of MRP preceding crop of maize combined with different culture systems are shown in Fig. 1.

It is observed that the layer 50-100 mm deep showed significant differences in MRP values, and the sunflower culture associated with CC provided higher MRP values. The degradation of the soil structure along the profile can be attributed to the intensive use of agricultural mechanization adopted in CC [16], resulting in soil compaction as a function of plowing and operations by grading [17]. These operations performed at the same depth and direction in the soil even though associated with favorable soil moisture can increase soil compaction [18]. It is observed that the MRP values in this layer exceed 2500 KPa, reaching values higher than 4000 KPa.

[13] state that MRP values up to 2500 KPa are considered low and show little limitation on root development. High MRP values increase resistance to root growth [19], reduction in total soil porosity by reducing water storage and

restriction of gas flow [20]. The large spatial variability of the mechanical resistance to penetration presents a series of implications for root and shoot growth [21].

The MC system showed no significant difference between the MRP values and different cultures antecedent to maize (Fig. 1). However, the crotalaria crop when used in succession with maize provided higher MRP values in relation to the other treatments at depths 150-200 and 200-250 mm (Table 2), probably due to the lower contributions of the plant residues left by the plants used as cover [22], and higher tillage of the soil that led to the destruction of the larger aggregates in smaller aggregates and to the soil particle size distribution [23].

The lower MRP values were obtained with the millet previous crop, resulting in a favorable development condition for the maize crop, depending on MRP. However, in the superficial layers (0 - 100 mm), the systems with higher soil mobilization (CC and MC) had lower MRP values when compared to NT. Values below 2000 KPa, providing a favorable condition for root development, according to [24], when they affirm that in CC systems, where the surface layer of the soil is periodically revolved, it is common to observe the momentary increase of the macroporosity values, possible reason why areas submitted to the CC have smaller values of MRP in the superficial layer of the soil.

Although the average pressure exerted on the surface layers is less than 2500 KPa, in some places these values reached 4500 KPa, resistance considered high, where in this situation it can present limitations to the development of the root system of the plants, and can be explained by the values of [25].

However, [26], states that the compacted soil layer does not present as a continuous mass, where there are spaces of MRP of variable values, and the roots in its development look for the free spaces in the soil and the method of measurement of MRP, not being the adopted method, capable of identifying and integrating the effect of cracks, of biological pores in the soil, tortuous pores, which is why the roots can develop in these regions of lower resistance, even though in the analysis high values of MRP.

In the NT system, the highest MRP values were obtained with the use of the sunflower crop as an antecedent crop to the maize, being the most outstanding values in relation to the other crops, mainly in the superficial layer (100 to 150 mm), reaching around of 4500 kPa. However, the crotalaria culture was the one that contributed with lower MRP values along the profile, concluding that its root system developed in better condition. This was probably due to the roots of the pivotal type, which provide the presence of biological pores, decomposition of the same associated to the non-revolving soil, as reported Reinert, et al. [27]. According to Schmidt, et al. [17] the conservationist systems provided increased soil fertility, especially in relation to the exchangeable bases and soil organic matter content, motivated by legume species that favored increases. Thus, although compaction has occurred as discussed above. Soil organic matter and corn productivity are the main substrates for the difference between maize growing systems and predecessor plants.

However, in the deeper layers, the conditions of resistance gradually decrease in all depths, according to the years of implantation of the no-tillage system, a fact that depends on the benefits that such a system provides to the soil [6], such as the accumulation of organic matter at the surface, associated with macro and microfauna, which play a significant role in soil physical properties [8].

It was observed in the minimum cultivation that the millet crop when used before corn, provided lower MRP values by its dense and fasciculated root system, taking advantage of small cracks or cracks to develop in the soil. Calonego, et al. [28] millet (Pennisetum glaucum (L.)) has become a good cover crop option, providing high amounts of dry matter mass, allowing the dry winter Species with higher C/N ratio, such as millet, should be potentially used in MC and NT, because the larger the ratio, the slower the decomposition of residues and the greater the physical protection of the soil, bringing benefits to agroecosystems, markedly in tropical regions , due to the effects of concentrated rainfall and intense direct solar radiation.

In Fig. 1, it is possible to observe also the high increase in MRP values from 250 mm deep, probably due to the presence of the textural B horizon in this soil, with a high clay content, making it less permeable and contributing to its densification, associated with low humidity values, mean that the high cohesion of these soils of Tablelands provides high values of MRP, a typical situation occurring in the Ultisols of this region in the State of Sergipe.

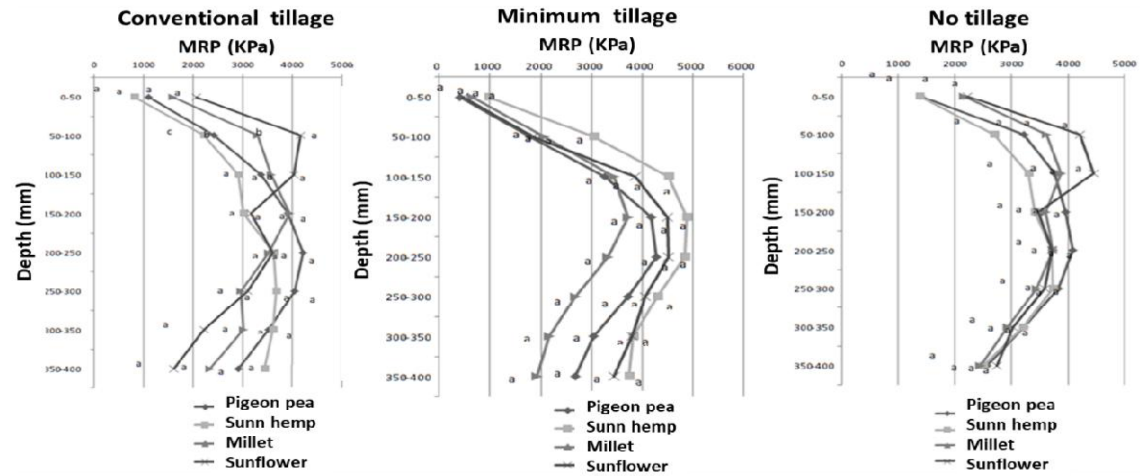

Fig. 1. MRP along the soil profile for different antecedent cultures associated to the different cropping systems. Equivalent letters for the same depth interval do not differ statistically by the Tukey test at the 5% probability level

Table 1. Gravimetric soil moisture values for different antecedent cultures associated with different cropping systems

Cultures	Moisture (kg kg^{-1})		
	CC[1]	MC	NT
Pigeon pea	0,500 bA[1]	0,387 cB	0,293 bC
Millet	0,571 aA	0,551 aA	0,424 aB
Crotalaria	0,454 bA	0,424 bA	0,403 bA
Sunflower	0,419 cA	0,424 bA	0,290 cB

[1]Different lowercase letters in the column and different capitals in the row, differ statistically by the Tukey test at the 5% probability level

Table 2. Maize productivity when submitted to previous cultures associated with different cropping systems

Culturas	Productivity of Ears (kg ha^{-1})		
	CC	MC	NT
Pigeon pea	6.373,4 aC[1]	8.287,0 aB	9.830,2 bA
Millet	3.935,2 cC	6.589,5 cB	9.930,2 aA
Crotalaria	5.663,6 aB	9.722,1 aA	10.000,0 bA
Sunflower	5.370,4 bC	7.145,0 bB	12.762,3 aA
Mean	5.335,6 C	8.005,4 B	10.536,2 A

[1]Different lowercase letters in the column and different capitals in the row differ statistically by the Tukey test at the 5% probability level

Oliveira, [29], also found high MRP values from the 250 mm layer, which probably is due to the textural gradient by the beginning of the textural B horizon, providing lower permeability of the B horizon due to the increase of the clay fraction. In this condition, with low humidity leads to a lower lubricating effect of the water around the soil particles and, consequently, to higher values of MRP. This behavior is also related to texture, where sandy soils present lower MRP than clayey soils due to the lower manifestation of cohesion between sand particles and clay particles, markedly more pronounced in small summer.

In general conditions, in the NT system in relation to CC and MC, they presented two regions with higher MRP values in the superficial layer. [13], state that the greatest compaction state in no-tillage occurs up to 100 mm deep, this being attributed to the confinement of the pressures resulting from the traffic of machines, for the different agricultural operations, besides the natural accommodation of the soil. According to Ralish, [30] in general, these conditions verified in the NT demands less labor and energy, stimulates the flocculation and aggregation processes, reduces the mineralization velocity of the soil organic matter, minimizes erosion , but on the other hand, it favors the appearance of compaction due to not revolving soil and excessive traffic of agricultural machinery and implements.

In Table 1, the NT system presented a significant difference in relation to the other systems studied. In the MC system, the antecedent millet culture provided lower values of MRP, precisely at the depth where the moisture values were relatively high, in relation to the others. Similar behavior was observed in NT when the antecedent culture of sunflower was used, where its moisture was relatively low, and consequently the values obtained of MRP were high.

These results are in agreement with [31], who state that soils with low moisture values tend to increase the cohesion and consequently the MRP values, causing higher pressures in the root hood to develop in the soil. [32], state that the degree of compaction may become limiting, according to the variations of humidity, that affect the MRP, making critical the supply of water and nutrients to the crops.

This scenario became relatively common in the tablelands soils, being this type of formation due to climatic conditions associated to the characteristics of the textural B horizon, and they present a hard to very hard, when dry, and friable when wet [33]. And as a consequence, their growth and productivity are affected due to water and nutritional deficits. Evidences of this type have been observed in the citrus and eucalyptus farms in the south central region of Sergipe, in areas of Ultisols, causing a decrease, respectively in the useful life of the orchards and lower wood production, due to the presence of cohesive layers. These results are in agreement with [13], that working with the establishment of MRP index to quantify the degree of cohesion, observed that where the values of MRP are higher are also due to lower values of soil moisture. [34], due to this behavior, in the detection of compacted layers, it is necessary to follow the respective values of soil moisture.

One of the challenges in the use of conservation systems in farms in tropical regions is the formation and maintenance of mulch, as well as the recycling of nutrients by the decomposition of organic matter sources, associated with efficient soil cover, protecting the same against high levels of solar radiation and intense rainfall, contributing to the rapid decomposition of organic matter and erosion propensity, as well as increasing the residence time of the water in the soil profile. However, in the edaphoclimatic conditions of the study, this period is increased, due to the intense decomposition of the organic matter soil caused by the high solar radiation of the region and the occurrence of erosion in the surface, due to the sandy and B texural (clay) horizon associated with inefficient vegetation cover and slope typical of the Ultisols, predisposing to problems commercial crops.

In Table 2 are showed the yield values of maize cultivated under different antecedent cultures associated to the cultivation systems in the fifteenth cycle of the experiment.

It was observed a significant difference in the values of ear yield when cultivated among the different cultivation systems, except for the culture of the crotalaria when cultivated in the MC and NT systems (Table 2). The highest values were obtained in NT, followed by MC. The increment of ear yield in NT and MC was 50% and 97%, respectively, in relation to CC (Table 2). These data are in accordance with the studies obtained by [35], who study variables of influence on maize yield in a commercial crop under no-tillage, emphasizes the importance of this cropping system. [36], observed that CC promoted higher MPR than the other systems studied, hindering the development of maize crop, impairing root penetration, impairing the absorption of nutrients essential for its development, resulting in low production rates.

Within each of the cultivation systems studied, a significant difference was observed in maize productivity, when different cultures were used in succession, and the same influenced differently for each cultivation system. In the NT, the sunflower crop contributed to higher levels of productivity, in MC it was the cultivar of the crotalaria and in the CC the culture of the pigeon pea. However, it should be noted that, in general, all crops in succession have resulted in higher yields in conservation systems, with significantly different values and greater expression when adopting the NT system (Table 2). [37], covering plants, when employed in succession in vegetative practices and in an adequate manner,

Table 3. Mean values of corn and ears plants, percentage of plants with commercial ears in different cropping systems after the use of previous crops

Cultivation system	Number of plants ha^{-1}	Number of ears ha^{-1}	Relation number of plants with ears and total of plants (%)
CC	45.216,0 a[1]	23.837,3 b	52
MC	49.498,4 a	33.873,4 a	68
NT	42.797,8 a	34.194,4 a	79

[1]Different vertical vertices differ statistically by the Tukey test at the 5% probability level

result in effective erosion control, restoring maintenance, resulting in increased crop productivity, causing less damages to the environment, ensuring the sustainable development of agroecosystems.

Table 3 refers to the efficiency of corn plants in the production of commercial ears, expressed by the relation between plants and commercial ears. It is observed that there was a significant difference at the 5% probability level for the parameters number of commercial ears per hectare.

Analyzing the values expressed in Table 3, it is observed that, in the fifteenth year of conduction of the experiment, although CC had a larger number of plants/ha, and the number of commercial ears was lower with statistically significant difference than in the systems conservationists MC and with prominence, the NT. In this way, it is highlighted the higher efficiency of NT in converting its maize plants with high number and weight of the commercial ears. This behavior can be attributed to the favorable physical, chemical and biological conditions of the soil, provided by the non-revolving soil, creation and maintenance of the mulch on its surface, besides the efficient recycling of nutrients and residual fertilization of the crops in succession , all these aspects and in an integrated way, as reported above, markedly in relation to the behavior of the mechanical resistance of the soil penetration.

4. CONCLUSIONS

In the edaphoclimatic conditions of the tablelands, after fifteen years, it was observed that the NT system provides better levels of maize productivity coupled with lower MRP values along the profile. Under general conditions, the lowest MRP values were located in the superficial layers in the CC and MC and higher in the NT. In general, the use of pre-corn crops contributes to the reduction of MRP values, especially in the NT, providing higher levels of maize productivity, compared to the CC and MC systems. Conservation systems are a viable alternative to obtain lower values of MRP combined with higher productivity of commercial ears of green corn, because the productive efficiency reached in these systems was higher than that obtained under CC, by more than 50%.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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