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Article

Soil structural quality and development of second-crop corn intercropping with forage grasses under no-tillage

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ABSTRACT: The intercropping of corn with forage grasses increases soil cover and may improve soil structural quality. The objective of the study was to evaluate the soil structural properties and the development of second-crop corn intercropping with forage grasses under no-tillage system. The experiment was carried out in an area of Sítio Santo Antônio, located in the municipality of Borrazópolis, Paraná state, Brazil, on a Red Latosol with a very clayey texture. The experiment consisted of five treatments: corn + *Urochloa brizantha* cv. Marandu (T1), corn + *Urochloa brizantha* cv. Piatã (T2), corn + *Urochloa brizantha* cv. Xaraés (T3), corn + *Urochloa ruziziensis* (T4), and non-intercropping corn (T5). In the corn crop, the following characteristics were evaluated: plant height, first ear in insertion height, stem diameter, corn yield, dry mass of corn straw mulch, dry mass of grasses shoots and dry mass of grasses root. Dry mass of the aerial part and roots of the grasses were evaluated. In the 0–0.10 and 0.10–0.20-m soil depth, soil physical properties were also determined: tensile strength and friability, stability of aggregates, bulk density and total porosity, and degree of compactness. The treatments of corn in intercropping with grasses showed positive results regarding the stability of aggregates, reduction of bulk density and increase of total porosity in the 0–0.10-m soil depth. The intercropping of corn + *U. ruziziensis* showed the lowest values of degree of compactness and higher production of dry mass of the aerial part.

Key words: soil physics, crop production, soil cover.

INTRODUCTION

In Brazil, 32.8 million hectares are cultivated under no-tillage system (Soares et al. 2021), being characterized by the double crop of soybean-corn, where soybean is grown in the summer and corn at the end of the season (Anghinoni et al. 2021, Mendes et al. 2018). The state of Paraná is one of the largest producers of second-crop corn, in which the north and western regions of the state are the main producers of this grain (Paschoal et al. 2020).

However, despite the numerous benefits of no-tillage system (Ferreira et al. 2020, Vizioli et al. 2021), the use of increasingly heavy machinery has generated degradation of the soil's physical structure, mainly in the topsoil layer (Martínez et al. 2016). The straw cover generated by a single crop in no-tillage system is often not enough to adequately cover the soil throughout the year (Pariz et al. 2016) and protect it from the numerous pressures exerted by agricultural machinery (Ferreira et al. 2020). In this sense, the use of forage grasses intercropped with second-crop corn has been used in no-tillage system (Silva et al. 2021). Several authors have verified the beneficial effects of forage grass intercropping with second-crop corn (Brandão and Silva 2012, Calonego et al. 2017, Cagna et al. 2019, Favilla et al. 2020).

Forage species of the genera *Urochloa* and *Panicum* produce large volume of dry mass, essential for the soil covering in no-tillage system. These forages present high C/N ratios, reducing the soil organic matter decomposition rate and protecting the soil from erosive processes and solar radiation (Cagna et al. 2019, Santos et al. 2021). Together with corn, forages produce large amounts of dry mass, increasing residue production and promoting positive effects on soil physical properties (Calonego et al. 2017, Favilla et al. 2020) and on the yield of subsequent crop (Santos et al. 2021), commonly soybean. Santos et al. (2021), evaluating soybean yield in a corn with forage grass intercropping system, observed that intercropping systems increased soybean yield due to improvements in soil physical quality.

The hypothesis of the study was that intercropping of corn with forage grasses promotes improvement in the soil physical quality and in the development of second-crop corn. The objective was to evaluate the soil structural properties and the development of second-crop corn intercropping with forage grasses under no-tillage system.

MATERIAL AND METHODS

The experiment was carried out in an area of Sítio Santo Antônio, located in the municipality of Borrazópolis, state of Paraná, Brazil, at coordinates 23°52'S and 51°32'W, at an average altitude of 447 m. In the region, the average annual precipitation and temperature are 1,556 mm and 19.4°C, respectively. According to Köppen's climate classification, the climate of the site is humid subtropical (Cfa). The soil of the area is classified as Red Latosol with a very clayey texture (Santos et al. 2018). The granulometric analysis indicated the values of 175 $g \cdot Kg^{-1}$ of sand, 685 $g \cdot Kg^{-1}$ of clay, and 140 $g \cdot Kg^{-1}$ of silt in the 0–0.20-m soil depth. The experiment area has adopted the no-tillage system since 1997, and the main crops over the years have been corn (*Zea mays* L.), soybean (*Glycine max* L.) and wheat (*Triticum* spp.).

The experiment consisted of five treatments: corn + *Urochloa brizantha* cv. Marandu (T1), corn + *U. brizantha* cv. Piatã (T2), corn + *U. brizantha* cv. Xaraés (T3), corn + *Urochloa ruziziensis* (T4), and non-intercropping corn (T5). Each experimental plot was 95-m long and 9-m wide. It was installed on March 5, 2018, where the grasses were first sown using a seeder (Semeato TD 300, 19 rows) with a seed volume of 30 $seeds \cdot m^{-2}$, followed by the corn (hybrid AS 1777 VT PRO3, Agroeste), using a seeder (Planti center Terraçu's articulated, 10 rows), with a row spacing of 0.50 m.

To determine tensile strength (TS) and aggregate stability (AS), undisturbed soil samples were collected at 0–0.10 and 0.10–0.20-m soil depth, collected after desiccation of forage grasses on October 30, 2018, and in each treatment two random points were selected in the plot.

TS and AS were determined from aggregates obtained from undisturbed soil samples, which were manually de-crushed into their natural aggregates and air dried for 48 hours. The aggregate sizes used in the determination of TS were those retained between sieves of 19- and 12.5-mm diameter, according to the methodology described in Imhoff et al. (2002). For AS, the aggregates used were those retained between 4- and 2-mm mesh sieves.

The TS was measured using a bench penetrometer with penetration needle adaptation. The TS was calculated according to Dexter and Kroesbergen (1985) and Watts and Dexter (1998). Soil friability was estimated by the coefficient of variation method according to Watts and Dexter (1998). The friability classes used were adopted as proposed by Imhoff et al. (2002): non-friable ($F < 0.10$), slightly friable (F = 0.10 to 0.20), friable (F = 0.20 to 0.50), very friable (F = 0.50 to 0.80), and mechanically unstable ($F > 0.80$).

The AS was performed by wet sieving according to the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA 1997) methodology. The weighted mean diameter (WMD) and the geometric mean diameter (GMD) were obtained as proposed by Castro Filho et al. (2002).

For the determination of bulk density and total porosity, undisturbed samples were collected in the 0–0.10 and 0.10–0.20-m soil depth. Ten samples were collected per treatment and depth. An Uhland auger and a 0.05-m diameter by 0.05-m high volumetric ring were used to collect the samples. The samples were dried in an oven at 105°C, for 24 hours, and then the bulk density was calculated. The total porosity was obtained using bulk density and particle density (2.65 $mg \cdot m^{-3}$).

For sampling the degree of compactness five random points were selected in the plot. At each point, disturbed samples were extracted at 0–0.10 and 0.10–0.20-m soil depth. To obtain the compaction curve, the Normal Proctor test was performed (ABNT 2016). From the compaction curve, the critical bulk density and then the degree of compactness were calculated.

The evaluations of the corn crop were performed in 10 random points per treatment, where it was measured 1 m per point, on September 8, 2018, being determined the following characteristics: plant height, first ear in insertion height, and stem diameter. The plants arranged in the seedling line were analyzed. The corn yield was determined (corrected to 13% humidity), as well as the dry mass of corn straw mulch (performed after the corn harvest), and the samplings were performed with the help of a 0.25 × 1.0 m gauge. All the material belonging to the corn was collected in the area of the template, taken to an oven at 65°C for 72 hours, and then the dry mass was converted into $kg{\cdot}ha^{-1}$.

The evaluations of the forage grasses were performed on October 15, 2018, 23 days after corn harvest and desiccation. To evaluate the dry mass of grass shoots, the cut was made 0.05 m from the soil surface with the help of the template with dimensions 0.25 × 1.0 m, randomly launched. Three replications were performed in each treatment. To evaluate the dry mass of grass roots, the plants were carefully pulled inside the template to avoid as much as possible the loss of roots. Both the aerial part and the roots were dried in an oven at 65°C for 72 hours, and then the dry mass was converted to $kg{\cdot}ha^{-1}$.

The confidence interval of the mean was adopted as a statistical criterion for discrimination and comparison of the effects of the intercropping on soil physical properties, corn, and forage grass characteristics. To obtain the confidence interval, the variance of data was calculated from treatment means, and then the standard deviation. The next step was to calculate mean standard error to be used in margin error. To calculate margin error, the t value on distribution table corresponding to significant level of 5% was obtained. Significant differences among intercropping systems were considered when there was no overlapping between upper and lower limits. The confidence interval establishes the values in which the average of the values of the data set is located and is an efficient and reliable method for interpreting significant differences in non-traditional experimental design (Payton et al. 2000).

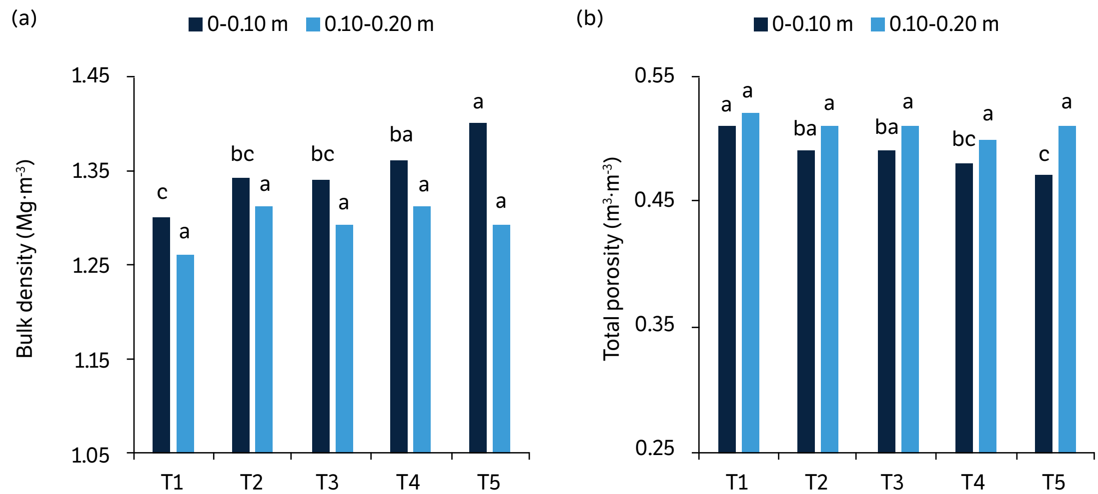
The principal component analysis (PCA) was performed to determine correlations between soil physical properties, and corn plant variables ($p < 0.05$), through the OriginLab software version 9.95 (OriginLab Corporation 2022). The data has not been transformed, and the vectors did not rotate. In addition, the data did not have covariance; they were independent of each other.

RESULTS AND DISCUSSION

Soil physical attributes

The treatments corn in intercropping with forage grasses influenced bulk density (Bd) and total porosity (TP) ($p < 0.05$) only in the 0–0.10-m soil depth (Figs. 1a and 1b). Treatment T1 (*U. brizantha* cv. Marandu) presented the lowest Bd (1.30 $mg{\cdot}m^{-3}$) and was statistically different from treatment T5 (non-intercropping corn) (1.40 $mg{\cdot}m^{-3}$) (Fig. 1a). Only treatment T4 (*U. ruziziensis*) was statistically equal to treatment T5. For TP, treatment T5 was 8% lower than treatment T1, significantly different from each other (Fig. 1b). There is a tendency for reduction of Bd and increase of TP in the 0.10–0.20-m soil depth, showing that the increase of soil Bd is restricted to the 0–0.10-m soil depth in non-intercropping corn (T5) when compared to the other treatments. These results show that the intercropping of corn + forage grasses was able to reduce Bd and increase TP, as evidenced by the treatments T1, T2 and T3. The highest value of Bd and lowest of TP found in treatment T5 is associated with the lower contribution of dry matter in the soil, leaving it more exposed to direct contact with raindrops, wheels of machinery and agricultural implements (Ferreira et al. 2020).

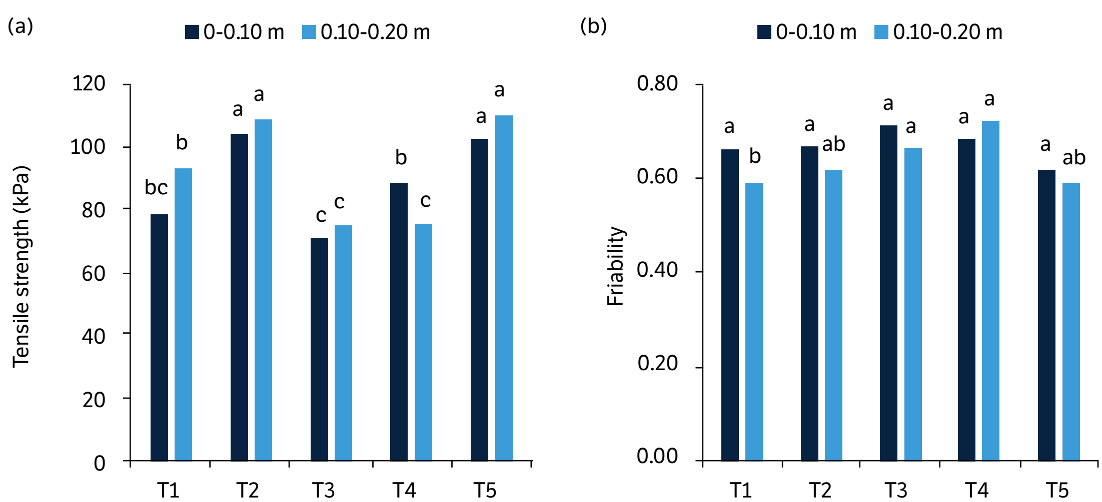
The intercropping of corn with forage grasses is a strategy to reduce soil compaction, as shown by the reduction of Bd and consequent increase of TP. These results corroborate with those of Calonego and Rosolem (2010), Pereira et al. (2016), Calonego et al. (2017) and Favilla et al. (2020), who indicated that management practices that provide the formation of biopores and macropores contribute to alleviate soil compaction. This occurs mainly due to the aggressive root system of grasses, with vigorous roots, with high capacity to develop in compacted soils, benefiting the subsequent crop (Calonego and Rosolem 2010).



Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn.

Figure 1. (a) Bulk density and (b) total porosity at 0–0.10 and 0.10–0.20-m soil depth.

Treatments T2 (*U. brizantha* cv. Piatã) and T5 (non-intercropping corn) presented the highest TS values in both layers studied and were statistically different from other treatments (Fig. 2a). Treatment T3 (*U. brizantha* cv. Xaraés) showed the lowest TS, and was statistically equal to treatments T1 (*U. brizantha* cv. Marandu) and T4 (*U. ruziziensis*) in the layers 0–0.10 and 0.10–0.20-m. The TS of aggregates was sensitive to soil physical conditions, in agreement with Tormena et al. (2008).



Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn.

Figure 2. (a) Tensile strength and (b) friability at 0–0.10 and 0.10–0.20-m soil depth.

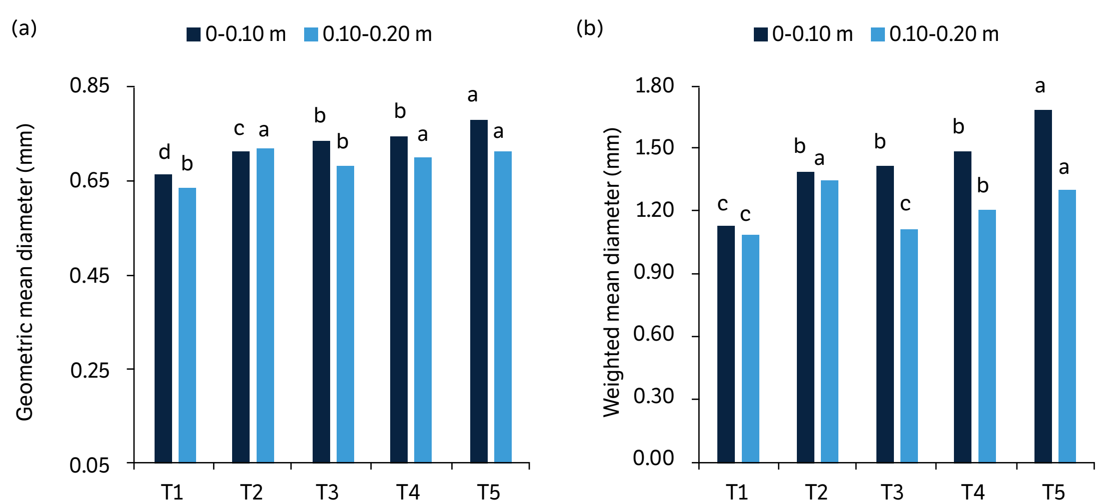
The lower value of TS obtained in treatment T3 is due to its more robust root system with thick roots that increases the volume of macropores and consequently the fragility points within the aggregates (Tormena et al. 2008, Cagna et al. 2019). It is observed that treatment T3 was able to provide homogeneity among the layers studied with TS values close to each other. This result is ideal for the development of the subsequent crop, which enables the roots to reach deeper layers of soil, improving the absorption of soil water. Guedes Filho et al. (2013) evaluated the long-term no-tillage system submitted to mechanical and biological chiseling. They found TS values like the present study. The authors also observed an increase in TS with increasing depth and justified it by the reduction of organic carbon.

Treatment T4 was the only one that reduced TS at depth (Fig. 2a); we hypothesize that this result is associated with the high volume of fine roots of *U. ruziziensis*, verified during root mass collections. Corroborating our results, Cagna et al. (2019) observed increased TS in non-intercropping corn, demonstrating that the absence of intercropping can leave the soil susceptible to the compaction process, since the pressures exerted by the machinery occurs directly on its surface (Pariz et al. 2016).

Treatments T1 and T5 showed the same F value and differed statistically from treatments T3 and T4 (Fig. 2b). The highest F value was obtained by treatment T4. Despite these differences, according to the classification proposed by Imhoff et al. (2002), all treatments in both layers were classified as very friable. Evaluating the influence of corn intercropping with forage grasses on physical attributes, among them the soil friability, Cagna et al. (2019) found no significant differences for F in the 0–0.10-m soil depth; in the 0.10–0.20-m soil depth F values were like those found in the present study.

Friability is an important physical indicator for monitoring soil structure, and the condition of friable soil is important for soils subjected to the no-tillage system (Tormena et al. 2008). Very low values of F are not desirable because it indicates that the soil can be fractured into fragments of arbitrary size when subjected to mechanical action. However, high values of F indicate that the soil can undergo intense turnover with minimal applied force, hindering crop establishment. The higher F values found in the intercropping treatments are due to the larger pore volume, which decreased TS and increased F (Bavoso et al. 2010, Cagna et al. 2019). Although the T5 treatment showed lower F in both layers when compared to the grasses, this indicates that in the long-term no-tillage system non-intercropping corn can promote reduction of its F and hinder crop development (Tormena et al. 2008, Bavoso et al. 2010), demonstrating the importance of forage grasses intercropping in grain production.

Non-intercropping corn (T5) presented the highest values of GMD (0.78 mm) and WMD (1.69 mm), differentiating itself statistically from all treatments intercropping with forage grasses (T1, T2, T3, and T4), at 0–0.10-m soil depth (Figs. 3a and 3b). At 0.10–0.20-m soil depth, treatment T5 showed the highest value of GMD (0.71 mm) and was statistically equal to treatments T4 and T2. For WMD, the highest value was found in treatment T2 (1.34 mm), statistically different from treatments T1 (1.13 mm), T3 (1.12 mm) and T4 (1.21 mm) (Fig. 3b). The lower values of WMD and GMD presented by the treatment T1 is attributed to the lower aerial and root development of *U. brizantha* cv. Marandu due to the drought that occurred during development and that especially affected this grass, indicating that it is less resistant to water deficit than the others.



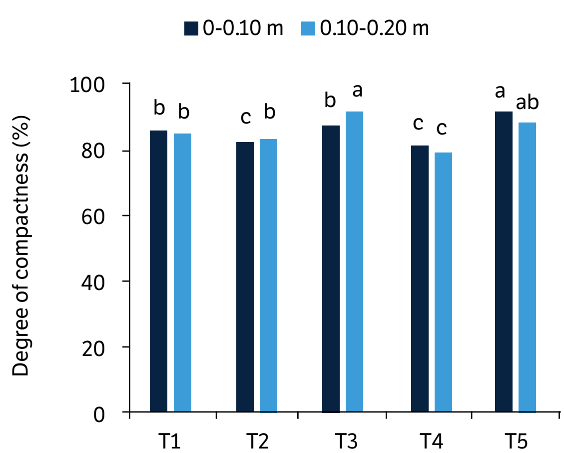
Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn.

Figure 3. (a) Geometric mean diameter and (b) weighted mean diameter at 0–0.10 and 0.10–0.20-m soil depth.

The WMD indicates the percentage of large aggregates retained on the larger mesh sieves, and the GMD is an estimate of the aggregate classes of higher occurrence. Thus, higher values of these indices indicate aggregate formation and stability of aggregates. The greater retention of residues on the soil surface promotes the storage of organic carbon, consequently the increase of aggregate stability by increasing the bonding forces between soil particles (Blanco-Canqui et al. 2013). Several authors have observed that increasing cover soil promoted increased WMD and GMD values (Guedes Filho et al. 2013, Cagna et al. 2019, Nouri et al. 2019). However, the intercropped treatments with higher ground cover showed lower WMD and GMD values than the treatment without intercropping.

In a long-term study with no-tillage and cover crops, Nouri et al. (2019) observed greater aggregate stability in systems with cover crops compared to fallow. This study evidenced that the effect of improving aggregate stability (WMD and GMD) by grasses in intercropping with corn can be achieved in the long term. Thus, the results of the present study may be associated with the short-term of the experiment. The lower values found in the intercropped treatments may be related to the biological decompaction promoted by the grass roots, which was evidenced by the results obtained for Bd, TP, and TS. Observing the variations in the values of WMD and GMD in both layers, the grass used in treatment T4 (*U. ruziziensis*) promoted greater stabilization of aggregates, when compared to the grasses of the other treatments, also noted by Brandão and Silva (2012). Although treatment T5 showed greater stability of aggregates, this may be associated with a greater densification of the soil that promotes greater stabilization of aggregates in wet sieving.

Similarly to the physical indices presented, the degree of compactness (DC) was also influenced by the intercropping of corn with forage grasses (Fig. 4). At 0–0.10-m soil depth, treatment T4 (*U. ruziziensis*) presented the lowest DC, statistically different from treatments T1 (*U. brizantha* cv. Marandu), T3 (*U. brizantha* cv. Xaraés) and T5. At 0.10–0.20-m soil depth, the treatment T4 showed the lowest DC, differing statistically from all treatments. The treatment T3 obtained the highest DC in this layer, being statistically equal to the treatment T5.



Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn.

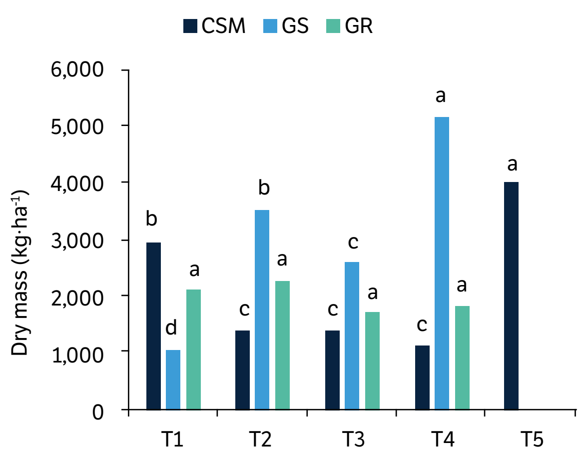
Figure 4. Degree of compactness at 0–0.10 and 0.10–0.20-m soil depth.

According to Reichert et al. (2009), in soils with clay content between 339 and 721 $g \cdot kg^{-1}$, DC between 80 and 88% is critical for the development of agricultural crops. Thus, the DC shows that treatment T5 (91.46) at 0–0.10-m soil depth is limiting for crop development, since the DC was greater than the limit of 88%. The cover crops have the potential to decompress the soil due mainly to the formation of biopores through their roots, which are usually well developed and resistant, promoting the decrease of DC (Chioderoli et al. 2012) and linear increase of TP (Suzuki et al. 2013). Consequently, with the decrease of the soil's Bd, the DC also decreases.

Thus, the treatments of corn intercropping with forage grasses were efficient in improving the soil's physical conditions; the *U. ruziziensis* (T4) stood out for presenting the lowest DC in both layers. During field sampling, it was observed that the grass used in T4 has thinner roots when compared to the other treatments, developing well in depth, and providing excellent soil coverage and root density over the layers. This provided reduction of DC in depth, being this grass favorable for DC reduction. Therefore, the results regarding the degree of soil compactness in this study proved the hypothesis that the use of forage grasses in intercropping with corn provides better physical conditions for plant root development.

Plant characteristics

The highest amount of corn straw mulch (CSM) was found in the non-intercropping corn (T5), while treatments T2 (*U. brizantha* cv. Piatã), T3 (*U. brizantha* cv. Xaraés) and T4 (*U. ruziziensis*) presented the lowest values (Fig. 5). Although CSM was low in these treatments, the dry mass coverage was compensated by grass shoots (GS). All treatments presented significant differences among themselves, treatment T4 presented the highest GS production capacity, and treatment T1 (*U. brizantha* cv. Marandu) presented the lowest value of this parameter. However, the treatments did not differ statistically in grass roots (GR).

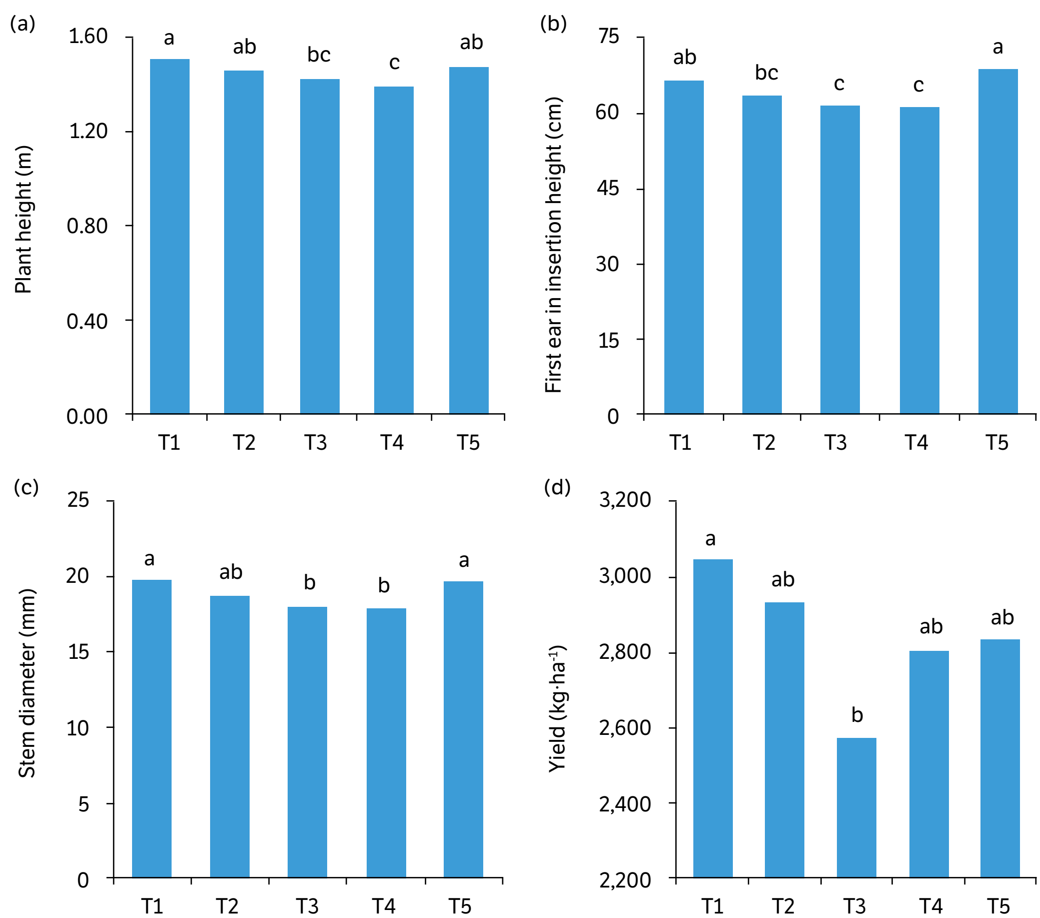


Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn; CSM: corn straw mulch; GS: grass shoots; GR: grass roots.
Figure 5. Dry mass of corn straw mulch, dry mass of grass shoots, and dry mass of grass roots.

Mariani et al. (2012), evaluating CSM and GS of non-intercropping and corn intercropping with three forage grasses, found lower values for GS and higher for CSM than those obtained in the present work. The authors observed that CSM was higher in the intercropping treatments when compared to non-intercropping. Higher GS values were found by Pariz et al. (2011); CSM production ranged from 2,750 to 6,440 kg·ha^{-1}. The lower production of GS in the present study as well as CSM was due to the water deficit during the experiment. The dry mass results of forage grasses showed the importance of using forage grasses for straw formation in the dry season, providing physical protection and moisture, contributing to the increase in soil organic matter content (Batista et al. 2019).

The agronomic variables of corn–plant height (PH), first ear in insertion height (EIH), stem diameter (SD), and yield were influenced by the intercropping treatments (Figs. 6a–6d). T4 (*U. ruziziensis*) showed the lowest PH, while treatment T1 (*U. brizantha* cv. Marandu) obtained the highest PH and was statistically equal to treatments T2 (*U. brizantha* cv. Piatã) and T5 (Fig. 6a). However, as mentioned before, the grass in treatment T1 presented a low development due to drought. Despite not interfering in corn development, this grass did not promote improvements in soil physical quality.

Paschoal et al. (2020), evaluating the soil structure by the visual method in this experiment, observed that the grass in T1 did not promote benefits in the physical structure of the soil due to the low development, and presented average visual score equal to the non-intercropping corn treatment. Reason why this treatment did not influence the variables observed in relation to non-intercropping corn (T5). However, the grass used at T2 showed good development and capacity to promote improvements in the physical quality of the soil, without interfering in the corn productive characteristics. The results of corn treatments with forage grasses demonstrate that the impact of forage grasses on corn crop characteristics depends on the grass species and cultivar used. Borghi et al. (2013), Ferreira et al. (2014) and Mingotte et al. (2021) did not observe the influence of the intercropping on PH.



Means followed by the same letter in the column do not differ significantly; T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn.

Figure 6. (a) Plant height, (b) first ear in insertion height, (c) stem diameter, and (d) yield.

Costa et al. (2012), evaluating agronomic characteristics of corn intercropping with *U. brizantha* and *U. ruziziensis*, subjected to doses of N under no-tillage system, obtained higher values than those found in this work for PH. Similarly, Pariz et al. (2011) also found higher PH values when evaluating corn intercropping with the grasses *U. brizantha*, *U. decumbens*, *U. hybrid* cv. Mulato II and *U. ruziziensis*.

Regarding EIH and SD (Figs. 6b and 6c), treatment T5 showed the highest value of these parameters, being statistically equal to T1. Treatment T4 obtained the lowest value of EIH and SD, being not statistically different from treatments T2 and T3. Analyzing EIH and SD of corn intercropped with *U. brizantha*, *U. ruziziensis*, *Crotalaria spectabilis,* and *Cajanus cajan* compared to non-intercropping corn in the southwestern region of Paraná, Oligini et al. (2019) showed higher values for EIH and lower for SD. The authors did not observe any influence of the intercropping on these traits. According to Costa et al. (2012), EIH and SD are important from the point of view of the ability to translocate nutrients to the cobs. A larger SD makes the corn crop more resistant to tumbling due to wind, rain and the traffic of machinery and implements. Thus, the grass *U. brizantha* cv. Piatã (T2) was the one that showed greater viability of the intercropping.

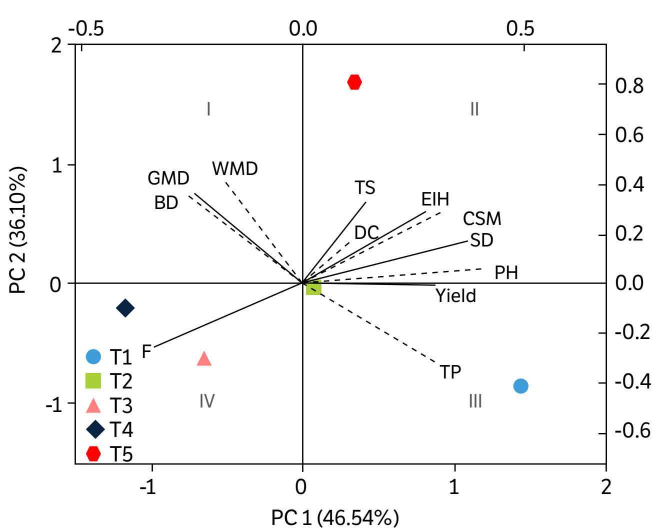
The yield (Fig. 6d) was lower in treatment T3 (2,573.39 kg·ha^{-1}), differing statistically from treatment T1, which obtained the highest yield among the treatments and did not differ from treatments T2, T4 and T5. The higher yield found in these treatments may be related to the SD, that is the structure responsible for the accumulation of soluble solids. Thus, the larger the DS, the greater the storage efficiency of photoassimilates, contributing to the support and formation of grains and possibly inferring in higher yield (Oligini et al. 2019).

Several authors have observed that depending on the forage species intercropping there can be reduction in corn yield compared to non-intercropping corn (Borghi et al. 2013, Costa et al. 2012, Ferreira et al. 2014, Mingotte et al. 2021). Ferreira et al. (2014) found that the grass *U. brizantha* is the hybrid that least influences the corn yield, like what was observed in the present study.

Values lower than those obtained in the present study for yield were found by Mariani et al. (2012). The authors evaluated these variables for non-intercropping corn and for corn in intercropping with *U. brizantha* cv. Marandu, *Panicum maximum* cv. Mombaça, and *P. maximum* cv. Aruana in a Red Latosol of clayey texture in the region of Passo Fundo, in Rio Grande do Sul, Brazil. The authors reported that the low yield results obtained in their study were due to the water deficit period during the crop cycle, corroborating what was observed in our study. Corn in general did not show good development, because it was a year in which precipitation was low during the experiment period, and the first precipitation after sowing corn and grasses occurred after 41 days.

Principal component analysis

The two principal axes, PC1 and PC2, explained 82.64% of the total variance of the data (Fig. 7). Based on the eigenvectors and their respective contributions, PC1 was most correlated with TS (3.89%), friability (F) (13.73%), DC (3.14%), CSM (11.75%), GS (12.14%), PH (13.71%), EIH (13.07%), SD (14.32%), and yield (5.20%). On the other hand, PC2 was better related to Bd (15.11%), TP (14.07%), GMD (15.84%), WMD (16.21%), and GR (13.07%) (Table 1). In Fig. 7 we can observe the distribution of treatments in quadrants I, II, III and IV. Treatments T3 (*U. brizantha* cv. Xaraés) and T4 (*U. ruziziensis*) showed a tendency to cluster in quadrant IV, and treatments T1 (*U. brizantha* cv. Marandu) and T2 (*U. brizantha* cv. Piatã) in quadrant III. The variables TS, DC, EIH, CSM, SD, PH are responsible for the discrimination of the T5 treatment. TP and yield are the most relevant variables for treatments T1 (*U. brizantha* cv. Marandu) and T2 (*U. brizantha* cv. Xaraés). The variable of most importance for treatments T3 (*U. brizantha* cv. Xaraés) and T4 (*U. ruziziensis*) was F.



T1: corn + *Urochloa brizantha* cv. Marandu; T2: corn + *Urochloa brizantha* cv. Piatã; T3: corn + *Urochloa brizantha* cv. Xaraés; T4: corn + *Urochloa ruziziensis*; T5: non-intercropping corn; GMD: geometric mean diameter; WMD: weighted mean diameter; BD: bulk density; TP: total porosity; DC: degree of compactness; EIH: first ear insertion height; CSM: dry mass of corn straw mulch; SD: stem diameter; PH: plant height; TS: tensile strength; F: friability; GS: dry mass of grass shoots; GR: dry mass of grass roots.

Figure 7. Principal components analysis of soil and plant variables.

Table 1. Correlations and contribution between evaluated parameters with two first principal components.

Variables	PC1		PC2	
	Eigenvalue	Contribution (%)	Eigenvalue	Contribution (%)
Bulk density	-0.12	1.55	0.39	15.11
Total porosity	0.17	2.84	-0.38	14.07
Tensile strength	0.20	3.89	0.19	3.77
Friability	-0.37	13.73	-0.08	0.60
Geometric mean diameter	-0.11	1.18	0.40	15.84
Weighted mean diameter	-0.04	0.13	0.40	16.21
Degree of compactness	0.18	3.14	0.14	1.83
Dry mass of corn straw mulch	0.34	11.85	0.15	2.31
Dry mass of grass shoots	-0.35	12.14	-0.08	0.57
Dry mass of grass roots	-0.16	2.42	-0.36	13.07
Plant height	0.37	13.71	-0.10	1.08
First ear in insertion height	0.36	13.07	0.13	1.65
Stem diameter	0.38	14.32	0.00	0.00
Corn yield	0.23	5.20	-0.15	2.25

The principal component analysis showed that treatments T1 (*U. brizantha* cv. Marandu) and T2 (*U. brizantha* cv. Piatã), distributed in quadrant III, represent high productivity associated with increased TP. Thus, the grasses used in treatments T1 and T2 showed a tendency to improve the physical quality of the soil, by increasing the TP, with consequent benefit to corn productivity. The principal component analysis also showed that TP was negatively correlated with Bd, GMD, and WMD, showing that the roots of grasses provided greater TP and increased the weak points of aggregates, reducing GMD and WMD, confirming that the lower GMD and WMD found in the corn treatments intercropping with forage grasses are associated with the short implementation time (Nouri et al. 2019). Treatments T3 (*U. brizantha* cv. Xaraés) and T4 (*U. ruziziensis*), in quadrant IV, are related to soil F. In quadrant II, the T5 treatment is related to increased SD, dry mass of CSM, PH, and EIH. Despite the improvement in corn plant characteristics, the T5 treatment is also related to the trend of soil physical degradation (Anghinoni et al. 2019), as it was directly related to an increase in the DC and TS of aggregates. Principal component analysis highlights the ability of corn intercropping with forage grasses to improve soil physical structure and showed that in the long-term non-intercropping corn can lead to soil degradation (Brandão and Silva 2012, Calonego et al. 2017, Cagna et al. 2019, Favilla et al. 2020).

CONCLUSION

Corn in intercropping with grasses promoted reduction on Bd and increased TP in the surface layer.

The intercropping corn + *U. ruziziensis* have potential to reduce the DC and increase aerial dry mass production when compared to the other forage grasses.

The characteristics of corn showed that the species and cultivar used, *U. brizantha* cv. Piatã, did not harm its development, being an option for intercropping to improve the soil physical quality without reducing corn yield.

The principal component analysis showed that non-intercropping corn can cause over time degradation of the soil physical structure.

AUTHORS' CONTRIBUTION

Conceptualization: Guedes Filho, O. and Paschoal, M. C. G.; **Methodology:** Gagna, C. P. and Guedes Filho, O.; **Investigation:** Gagna, C. P., Guedes Filho, O., Paschoal, M. C. G., Mazzini-Guedes, R. B. and Siqueira, G. M.; **Writing – Original Draft:** Gagna, C. P., Guedes Filho, O., Paschoal, M. C. G., Mazzini-Guedes, R. B. and Siqueira, G. M.; **Writing – Review and Editing:** Gagna, C. P. and Guedes Filho, O.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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ERRATA

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The surname of the first author shows as:
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Should be:
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