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Effects of tillage options on soil physical properties and cassava-dry-matter partitioning

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ABSTRACT

Conservation tillage is efficient at reducing soil degradation, but affects soil physical properties, and leads to soil compaction, negatively impacting root production, and so it is rarely adopted by cassava cultivators. The objective of this study was to evaluate the dry-matter partitioning (DMP) during a full cassava season under different tillage methods. The effects of minimum tillage (MT), conventional tillage (CT) and no-tillage (NT) on soil water content, soil penetration resistance, macroporosity, microporosity and total porosity were evaluated at 70, 120, 230, 300 and 350 days after planting (DAP). Additionally, the DMP in cassava plants was evaluated every 30 days until 360 DAP at Botucatu, Brazil on an Alfisol soil. Our result revealed that the tillage type affected soil penetration resistance, macroporosity and total porosity as well as the dry matter content (DMC) on cassava leaf, stem, root and planted cutting. No significant difference was observed in total DMC. However, DMP differed significantly between 150 and 210 DAP, corresponding respectively to the root-thickening phase end and the dormancy phase beginning. The highest DMC of stem and planted cutting was observed in NT-developed plants. Shoot DMC was positively correlated with soil penetration resistance. CT and MT did not differ in root yield; hence, MT should be adopted instead of CT, as an effort to control soil erosion. NT increases the soil penetration resistance, and results in greater accumulation of DM in the stem and planted cutting than in the roots. Data suggest that increased soil penetration resistance under NT can decrease cassava root growth and induce the stem and planted cutting to play the role of storage organs.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important tropical roots crops due to the diverse uses of its starchy roots, leaves and stem as staple food, animal feed, energy production and industrial applications. Therefore, its production has been increased in Latin America, Africa and Asia. However, the capacity of cassava to produce reasonable yields under adverse edaphic conditions, marginal lands and conventional tillage has contributed to the intensification of soil depletion (El-Sharkawy, 1993; Howeler, 1994).

In cassava cultivation, normally, the initial operation for field preparation is tillage. Tillage is performed mainly in order to obtain a weed-free seedbed, incorporate fertilizer and improve biological, chemical and physical conditions of the soil such as water content, resistance to root penetration, porosity and density (Ferreras et al., 2000; Cavalieri et al., 2006).

The effect of tillage on soil properties varies according to both soil and crops (Howeler et al., 1993). The cultivation of cassava is usually done under conventional tillage (CT), which is characterized by mechanical manipulation of the soil. CT involves ploughing

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Abbreviations: MT, minimum tillage; NT, no-tillage; CT, conventional tillage; DMP, dry matter partitioning; DMC, dry matter content; DAP, days after planting; DM, dry matter; HI, harvest index.

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followed by one or two instances of harrowing. The mechanical soil disturbances, in addition to some cassava features such as slow initial growth (slow complete canopy cover) and the soil disturbance during harvesting (Gabriel Filho et al., 2000), increase the soil losses by erosion.

Previous reports laid great emphasis on conservation tillage as minimum tillage (MT) and no-tillage (NT), due to their low cost and their positive impacts on the environment (Cavalieri et al., 2006; Otsubo et al., 2008); moreover, NT may maintain soil humidity without negatively affecting the yield of such tuber crops as potatoes (Carter et al., 2005), cassava (Howeler et al., 1993; Jongruaysup et al., 2002) and sweet potatoes under irrigation (Nedunchezhiyan et al., 2012). Despite these advantages derived from conservation tillage, its yield variability, in different soil types, leads to a non-adoption of this conservative management for cassava (Fasinmirin and Reichert, 2011).

Some studies have shown that NT can decrease cassava yield (Oliveira et al., 2001; Pequeno et al., 2007; Odjugo, 2008); however, others have found that NT and CT do not differ in relation to cassava yield (Reining, 1992; Gabriel Filho et al., 2000; Otsubo et al., 2012), and sometimes NT can provide higher production (Otsubo et al., 2008) than CT. These results show that doubts persist about the effect of tillage on the productivity of tuberous roots, which may be related to partition of dry matter through different parts of the cassava plant.

The partitioning of dry matter among different parts of the plant, and its relationship with the physical soil properties, promoted by different tillage methods, are important parameters for understanding and modifying the management practices as an effort not only to improve the yield and quality of cassava tubers, but also to convince the cultivators to adopt conservation tillage.

This study was conducted to estimate dry-matter partitioning during a period of a full season in cassava as affected by conventional tillage, minimum tillage and no-tillage. These data will be helpful to understand whether tillage affects the dry matter accumulation or its partitioning; moreover, these results can support the adoption of conservation tillage for cassava cultivation.

2. Material and methods

2.1. Study site

The experiment was carried out at the College of Agricultural Sciences, São Paulo State University (FCA-UNESP) in Botucatu, Sao Paulo state, Brazil (22° 49′S, 48° 25′W, at altitude of 770 m and a slope of 3%). The climate, according to the Köppen classification, is a Cwa type characterized by hot, humid summer and dry winter. The levels of rainfall and temperature recorded during the experiment are presented in Fig. 1.

The soil in the experimental area is loam texture classified as Alfisol soil – 110 g kg^{-1} sand, 270 g kg^{-1} silt, 620 g kg^{-1} clay (Soil Survey Staff, 2010). The physiochemical composition of soil consisted of 30 g dm^{-3} organic matter (pH 4.7); 0.01 mol L^{-1} $CaCl_2$; 20 mg dm^{-3} P (resin); 1.4 mmol$_c$ dm^{-3} K; 28 mmol$_c$ dm^{-3} Ca and 11.7 mmol$_c$ dm^{-3} Mg, and 9.0%, 40.4% and 49.4% of macroporosity, microporosity and total porosity, respectively. The experimental area was sown with oats under conventional tillage in the previous harvest. Oat stubble and weeds presented in the area were desiccated with glyphosate N-(phosphonomethyl) glycine (2.000 g ai ha^{-1}) 10 days before tillage.

2.2. Experimental design and treatments

The experiment was set up in a split-plot design, with tillage as the main block and the harvest times as the plot. The main blocks measured 140 m^2, with 9 m length and 16 m width (11,110 plants.ha^{-1}) and each plot measured 3.6 m^2.

The main blocks were represented by three tillage methods – CT, MT and NT, and the plots were represented by twelve harvest times at equal intervals of 30 days (30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330 and 360 days after planting – DAP). Each treatment was replicated six times. The CT consisted of one ploughing (Tatu Marchesan® Model AF5) and two instances of harrowing (Tatu Marchesan® Model GAPCR 360) – to 20 cm depth; MT – consisted of two rotary hoeing (Cemag® Model MS 70) to 10 cm depth, whereas in NT no implement was used. The different tillage methods were adopted for the first time after several years of conventional tillage and were performed one day before planting cassava.

The plots were randomly selected for successive harvest and consisted of four plants; the remaining sample plants were always surrounded by one internal and two external borders. According to the conditions under which this study was carried out, the evaluations performed at 30–60 DAP, 90–120 DAP, 150–180 DAP, 210–300 DAP and 300–360 DAP corresponded to the following phases of cassava plant development: sprouting and formation of the root system, shoot development, thickening of the roots, dormancy and new root thickening phase, respectively.

2.3. Plant material and planting procedure

The stem cuttings of 20 cm length, 20 mm diameter with five buds taken from 12-month-old plants of cassava cultivar IAC 576-70 were used in the experiment. The cassava cultivar IAC 576-70 is considered to be sweet, and is widely cultivated in Brazil. The experiment was carried out from October 2010 to October 2011.

Furrows, fertilization and planting were performed on October 15, 2010 (one day after tillage). The opening of the furrows at 0.10 m depth and the fertilization (200 kg ha^{-1} of 02-20-20, N-P_2O_5-K_2O) were performed using a cassava planter fertilizer (Plantcenter®, Model Bazuca II)

The stem cuttings were planted manually in individual spaces measuring 1 m x 0.9 m. Four hand-weedings were performed during the first four months after planting, representing the single phytosanitary treatment in this experiment. No supplementary irrigation was applied in this experiment.

2.4. Evaluation of soil physical properties

Three samples in each main block at 0–0.10, 0.10–0.20 and 0.20–0.30 m depth were used to evaluate soil physical properties. Samples were taken at 70, 120, 230, 300 and 350 DAP. The water content was determined by the gravimetric method according to Embrapa (1997). The penetration resistance was determined using a semi-automatic mechanical penetrometer (Soil Control® – Model SC-60) at 0.30 m depth, applying pressure up to 5 MPa.

In order to measure the porosity, the soil was sampled in volumetric containers of 100 cm^3. The total porosity was assessed by measuring soil saturation (total volume of water-filled soil pores); microporosity was assessed using the tension table and a water column of 6.10^{-3} MPa; and macroporosity was calculated from the difference between total porosity and microporosity. All evaluations were performed according to methodologies described by Embrapa (1997).

2.5. Dry-matter determination

Four plants per treatment were harvested at each destructive sampling; the leaves, stem, roots, and planted cutting were collected firstly to evaluate the fresh weight and subsequently dried in an oven at 65 °C for 96 h with forced ventilation to obtain the

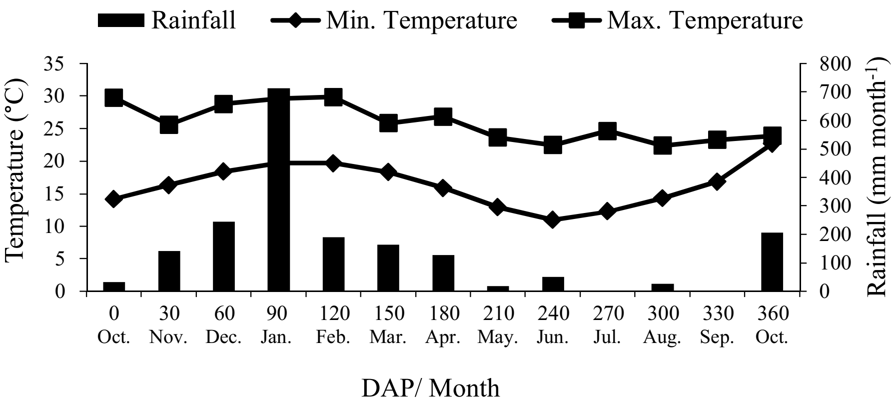

Fig. 1. Maximum and minimum temperatures and rainfall recorded during the experiment, October 2010–October 2011. DAP (days after planting cassava).

DM. These two data associated with plant population were used to evaluate the amounts of DM accumulated in the leaves, stem, roots and planted cuttings in kg ha^{-1}. The total dry matter was obtained from the sum of the DM accumulated in all parts of the plant, while the DM partitioning between plant parts was determined from the ratio between the amounts of DM accumulated in each plant part and the total plant DM. The harvest index (HI) was determined from the ratio between root DM and total DM.

2.6. Statistical analysis

The values related to soil physical characteristics were subjected to analysis of variance. The effect of the evaluation time was aggregated into one group in order to represent the general condition of the soil during the experiment. The least significant difference (LSD) test was employed to compare the three tillage mean values when a significant variation was highlighted by ANOVA. The differences were accepted as significant if $P < 0.05$.

The results in relation to the plant were subjected to ANOVA. The LSD test was utilized to compare the three tillage mean values when a significant variation was highlighted by ANOVA. The differences were accepted as significant if $P < 0.05$, and were shown through vertical bars in order to represent the LSD. The effect of the evaluation periods was assessed by regression analysis.

Additionally, the degree of association between mean values of the plant and soil variables was analyzed by the Pearson correlation. For the correlation analysis, the effect of the evaluation time was grouped, because the number of evaluations for the plant variables differed (30 – 360 DAP) from the number of evaluation times for soil physical characteristics (70, 120, 230, 300 and 350 DAP); furthermore, the tillage methods were clustered and analyzed all together due to the absence of correlations within each tillage method.

3. Results

3.1. The effects of tillage methods on soil physical properties

No significant difference was observed in soil water content and microporosity under the different types of tillage (Fig. 2a and d); however, NT showed high moisture in the upper soil layers (Fig. 2a). At all depths analyzed, the highest penetration resistance values were observed in NT and the lowest in CT (Fig. 2b). The MT presented the lowest values of macroporosity and total porosity, especially in the deeper soil layers, while the higher values of these variables occurred in NT in the layer from 0.10 to 0.20 m (Fig. 2c and e). In the 0.0-to-0.10 m and 0.20-to-0.30 m layers, the CT showed the highest macroporosity values (Fig. 2c).

3.2. The effects of tillage on cassava dry matter

In all the treatments leaf DM increased during crop emergence to 180 DAP and after 270 DAP, leaf DM was higher in plants growing under MT and CT, especially at 180 DAP (Fig. 3a).

The analysis of DM content in the stems revealed an increase of the DM amounts in all the treatments from 90 DAP until 300 DAP (Fig. 3b). At 150 DAP, the stem DM of the plants growing under NT was the highest compared to those growing under CT and MT (Fig. 3b). A positive correlation between the DM of shoots (leaves and stem) with soil resistance penetration was also observed during the experiment (Fig. 4a).

The planted cutting DM markedly increased in all treatments from 60 to 270 DAP, with no significant difference between treatments in the first 150 DAP (Fig. 3c). After 150 DAP the DM of planted cuttings from plants cultivated in NT was the highest in relation to the other forms of tillage (Fig. 3c). A positive correlation was identified between the DMs of planted cuttings and shoots (Fig. 4b).

In all treatments the DM of roots started to increase at 90 DAP until 210 DAP (Fig. 3d). Although the regression equations indicate augmented root DM from 210 to 270 DAP, the DM accumulated in the roots during this period remained relatively stable (Table 1). After this period the elevations in temperature and water availability induced a new increase of root DM (Figs. 1 and 3 d). Before starting the dormancy phase (up to 180 DAP), the root DM did not differ between treatments, however, at 210 DAP, plants cultivated under NT accumulated lower amounts of DM in the roots compared to the plants growing under CT and MT (Fig. 3d).

The DM amounts accumulated in roots did not differ significantly between CT and MT during the study cycle. The DM from roots was negatively correlated with those of shoots and planted cuttings (Fig. 4c and d), and positively correlated with the total DM (Fig. 4e). The total DM increased from 90 to 180 DAP, when the dormancy phase began. The total DM of cassava plants did not differ under the three tillage forms during the experiment (Fig. 3e).

The Harvest Index (HI) increased from emergence until 210 DAP, where plants of all treatments reached HIs of 60%. In subsequent samplings (240–360 DAP), the HI remained unchanged, but always higher in CT and MT compared to NT (Table 1).

4. Discussion

The cassava plant tends to grow continuously at different rates throughout the developmental phases. The duration of each phase may be influenced not only by the weather conditions – especially the water availability and temperature – but also the management (El-Sharkawy, 2006). According to our results, tillage or soil physical properties had no influence on the duration of cassava

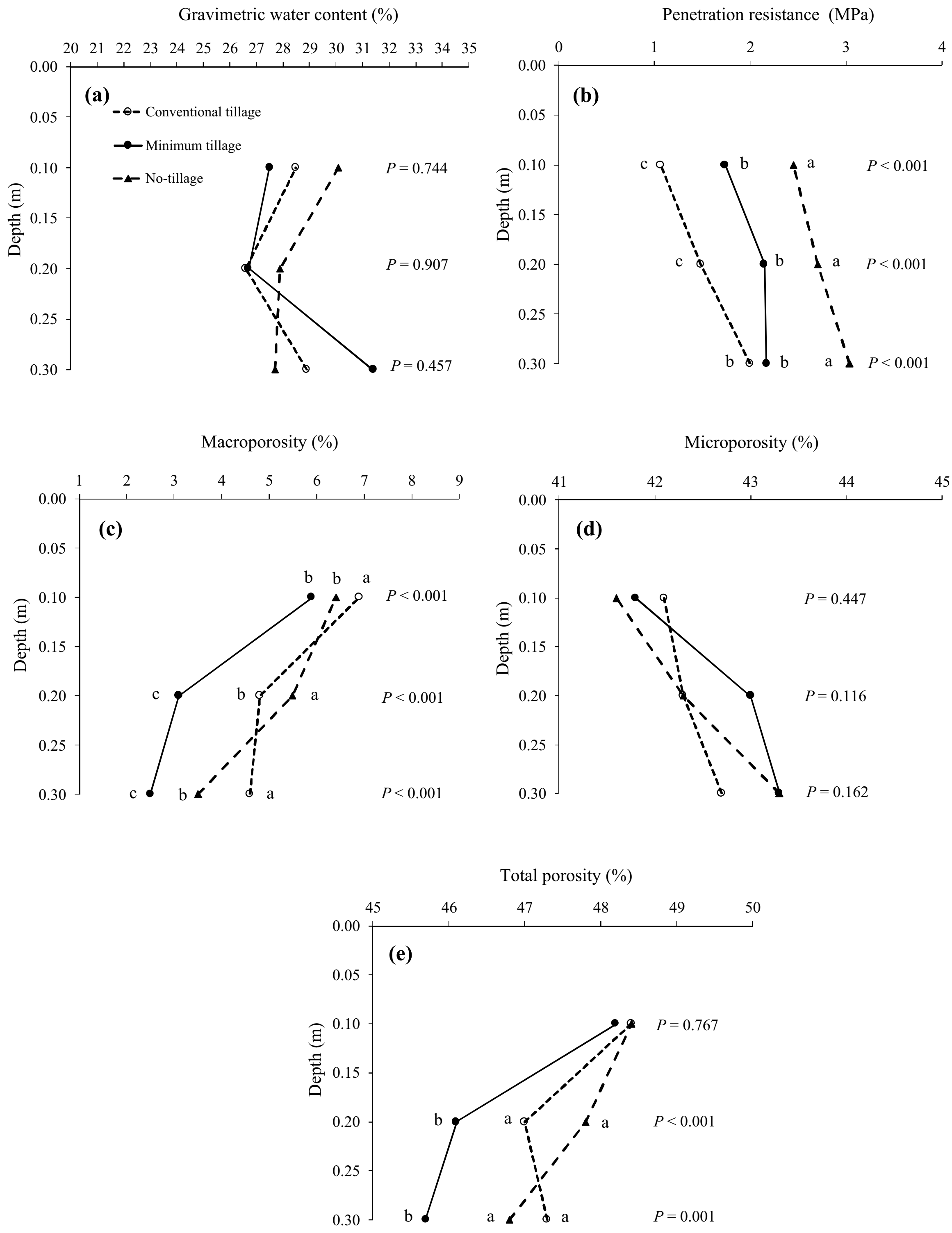

Fig. 2. Gravimetric water content (a), penetration resistance (b), macroporosity (c), microporosity (d) and total porosity (e) at different depths of soil subjected to conventional tillage, minimum tillage and no-tillage. Average of five evaluation times performed during the experiment. Different letters for each depth indicate significant differences between soil tillage, P < 0.05 by LSD test.

developmental phases, since the regression curves were similar across MT, CT and NT (Fig. 3). However, the main difference between the treatments occurred between 150 and 210 DAP, corresponding to the respective beginnings of the root thickening phase and dormancy phase.

The effect of tillage method on the developmental phases of soybeans and sweet potatoes had been investigated by Yusuf et al. (1999) and Nedunchezhiyan et al. (2012). These authors observed that the high resistance to root penetration and low water content in the soil, in NT, negatively affected the initial growth of these plants; however, the final yield (tuberous root, grain) was similar between those plants cultivated under CT and NT, due to a compensatory growth of these plants. This result is supported by Da

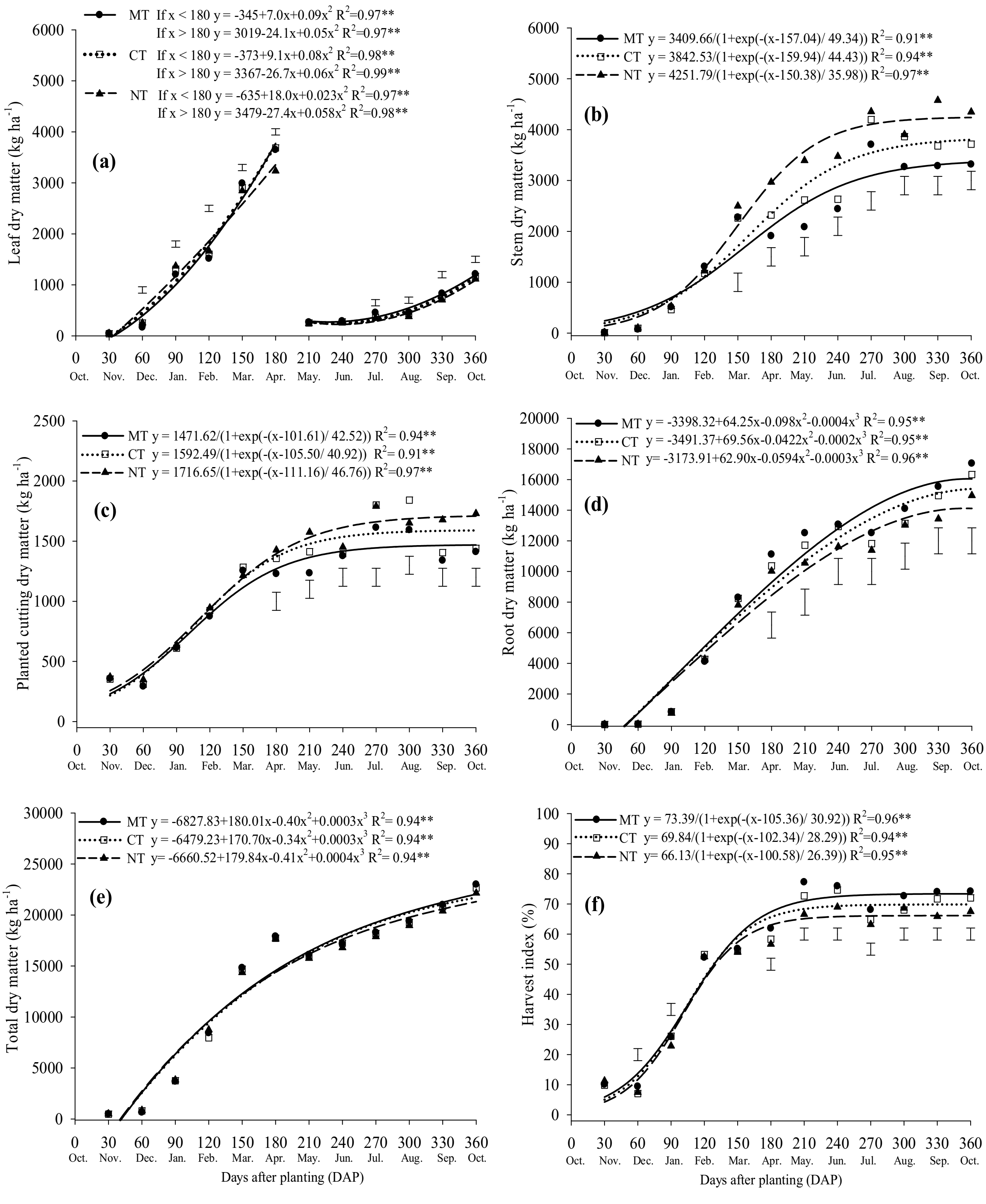

Fig. 3. Pattern of dry matter accumulation and partitioning in cassava plant during the full growth season. Dry matter partitioning in leaves (a), stem (b), planted cutting (c), root (d) and total (e), and harvest index (f) in cassava cultivar IAC 576-70, grown under different tillage. Vertical bars indicate least significant differences (LSD) between different tillage by LSD test. ** P < 0.01, by F-test.

Silva et al. (1994), who concluded that plants grown under this soil physical condition are more vulnerable in early seedling growth.

The absence of difference in the total DM between CT, MT and NT at all evaluation times shows that cassava does not possess a compensatory growth mechanism, as do sweet potatoes and soybeans. However, the difference in the DM partitioning though leaves, stem, planted cutting and roots, indicates that, when the tuberous roots face some mechanical resistance to their normal growth, the DM can be alternatively allocated to the stem and in the planted cutting.

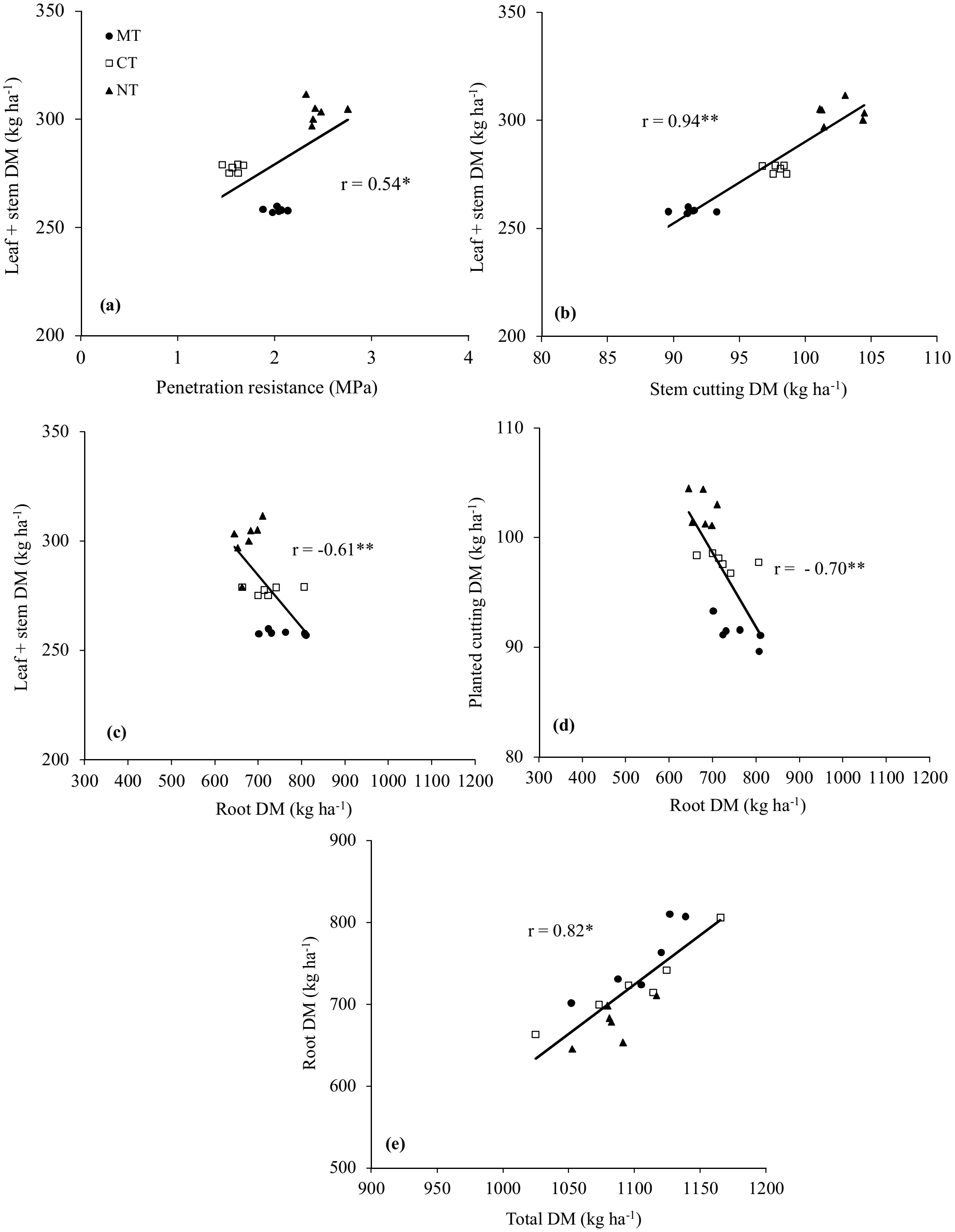

Fig. 4. Pearson correlation coefficients between soil physical characteristics and dry matter (DM) content of cassava organs. *, ** significant at 0.05 and 0.01, by F-test.

The stem and the planted cutting may compete with the tuberous roots for photoassimilates, as demonstrated through the negative correlation between them and root DM. The positive correlation between the stem DM and planted cutting DM suggests that, although the planted cutting is in the same spatial position of the roots (underground), its growth is physiologically similar to the stem, and hence both stem and planted cutting can differentiate some tissue toward the storage of carbohydrates.

Significant difference in root DM occurred at the beginning of the dormancy phase, where both water availability and temperature started to decrease. This environment condition might have contributed to the elevation of soil resistance penetration, since an average above 1.0 MPa was observed even in the superficial layers of CT (Figs. 1 and 2 B); this high value of soil resistance penetration is attributable to the fact that samplings were done at 230–350 DAP (root-thickening and dormancy phases), when precipitation

Table 1
Dry matter (DM) partitioning throughout the cassava plant variety IAC 576-70, grown under different tillage methods.

Plant Organs	Days After Planting (DAP)											
	30	60	90	120	150	180	210	240	270	300	330	360
	Minimum Tillage (MT)											
Root	0.02	0.05	0.26	0.52	0.55	0.62	0.77	0.76	0.68	0.73	0.74	0.74
Stem	0.02	0.13	0.16	0.17	0.16	0.11	0.13	0.14	0.20	0.17	0.16	0.15
Leaf	0.11	0.30	0.38	0.20	0.20	0.20	0.02	0.02	0.03	0.02	0.04	0.05
Planted cutting	0.85	0.52	0.20	0.11	0.09	0.07	0.08	0.08	0.09	0.08	0.06	0.06
	Conventional Tillage (CT)											
Root	0.01	0.04	0.26	0.53	0.54	0.58	0.73	0.75	0.65	0.68	0.72	0.72
Stem	0.02	0.14	0.14	0.15	0.16	0.13	0.16	0.15	0.23	0.20	0.18	0.16
Leaf	0.10	0.37	0.41	0.20	0.21	0.21	0.02	0.02	0.02	0.02	0.03	0.05
Planted cutting	0.87	0.45	0.19	0.12	0.09	0.08	0.09	0.08	0.10	0.10	0.07	0.07
	No-Tillage (NT)											
Root	0.02	0.04	0.23	0.52	0.54	0.57	0.66	0.69	0.63	0.69	0.66	0.67
Stem	0.03	0.14	0.16	0.15	0.17	0.17	0.22	0.21	0.25	0.20	0.22	0.20
Leaf	0.11	0.35	0.42	0.21	0.20	0.18	0.02	0.02	0.02	0.02	0.04	0.05
Planted cutting	0.84	0.47	0.19	0.12	0.09	0.08	0.10	0.08	0.10	0.09	0.08	0.08

was lower. Vine and Ahmad (1987) concluded that in the dry season, the decrease of water availability and the high soil penetration resistance accounted for the variation in cassava root yield.

Kaigama et al. (1977); Kätterer et al. (1993) and Alameda et al. (2012) reported that the high content of the water in the soil can promote fibrous root development in the upper layers of the soil. In our study, the water content in the upper soil layers in NT and the high penetration resistance might have induced the superficial development of fibrous roots, at the root system formation phase. This hypothesis can be supported by the earlier falling of the leaves, observed under this treatment at 180 DAP, which may be related to the difference observed in root DM at 210 DAP, and in the other yield components of cassava such as fresh matter and root diameter, as reported by Figueiredo et al. (2014).

The decrease of DM in the tuberous root of those plants under NT was associated with neither tuberous root morphology nor anatomy, as demonstrated by Figueiredo et al. (2014) and Figueiredo et al. (2015). However, it can be associated with the morphology and physiology of the fibrous roots as affected by porosity and soil resistance penetration, as shown by Hernandez-Ramirez et al. (2014).

An HI of 60% is considered ideal for optimum output of cassava (El-Sharkawy, 2006). It is important to note that the high HIs observed in all the treatments after 210 DAP were related to the reduction of leaf DM, since an HI above 70% is not common in cassava production. At almost all of our evaluation times, plants under NT had the lowest HI because these plants had higher stem and planted cutting DM. Some previous studies also demonstrated that cassava plants growing under NT resulted in a smaller HI (Oliveira et al., 2001; Pequeno et al., 2007; Odjugo, 2008), but at almost all of our evaluation times, no difference between CT and MT was observed.

Since both CT and MT provided to the plants similar, favorable conditions for root production, MT should be adopted instead of CT, as an effort to reduce soil erosion. Although the allocation of DM in the stem and in the planted cutting, observed in NT, is undesirable for agricultural production, the lower root yield in NT may be offset, in part, by a better cost-benefit performance of NT compared to CT (Fasinmirin and Reichert, 2011).

Is important to highlight that for cassava cultivation, no-tillage is related only to the manner of planting (without soil disturbance), which means that cassava cannot be included on a farm where the no-tillage system is adopted, because soil disturbance is unavoidable at harvesting. The effect of tillage on cassava yield is changed when such management is implemented for the long term (Pequeno et al., 2007). Further studies might address the duration that would be necessary for areas under NT to achieve satisfactory soil physical conditions for obtaining high yields.

5. Conclusions

Soil structural deterioration from continuous cropping systems can have a direct bearing on crop performance. The present study showed the differential effects of three tillage types on soil physical properties and their effect on cassava-dry-matter accumulation and partitioning up to 360 DAP. The minimum tillage must be used instead of conventional tillage based on the similarity of their root DM accumulation. No-tillage increases the soil penetration resistance, and results in greater accumulation of DM in the stem and planted cutting than in the roots. The data suggest that increased soil penetration resistance under NT can decrease growth of cassava roots and induce the stem and planted cutting to serve as a storage organ.

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