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SOYBEAN AND WHEAT RESPONSE TO CROPPING AND TILLAGE SYSTEM AFTER TWO DECADES IN AN OXISOL UNDER SUBTROPICAL CLIMATE IN BRAZIL

Desempenho de soja e trigo à sistemas de cultivo e de preparo após duas décadas em Latossolo em condições de clima subtropical no Brasil

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Abstract – No-tillage system have been a mainly conservationist system specially in tropical and subtropical climate conditions. The aim of this work was to evaluate yield components and morphological soybean and wheat in Rhodic Eutrudox under tillage and cropping systems in Subtropical climate (Londrina, Brazil, latitude 23º11'S; longitude 51º11'W; and 620 m in altitude). This study was carried with five tillage and two cropping systems, on completely randomized block design, with four replications. Tillage systems consisted of conventional tillage with disk harrow; minimum tillage with annual chiselling; minimum tillage with chiselling every three years; no-tillage for 11 years; and no-tillage for 24 years. The factor cropping systems was represented by crop rotation and crop succession. In the soybean crop were evaluated yield, mass of 1000 grains, plant height, and first pod insertion of soybean, chlorophyll content and the vegetation index normalized difference. Furthermore, for the wheat cropping was evaluated the grain yield and hectolitre weight. Soybean and wheat grain yields were not changed due to cropping systems. Soybeans yield in no-tillage with 24 years was higher than in conventional tillage; and soybean and wheat yields were not affected by times under no-till adoption. Soil chiselling not favoured increased in productivity of soybean and wheat. Thus, soil chiselling under this climate conditions is an unnecessary practice due to absence of productive and morphological improvement for soybean and wheat cropping.

Keyword: no-tillage system; long-term experiment; *Glycine max*; *Triticum aestivum*.

Resumo – O sistema plantio direto tem sido um dos principais sistemas conservacionistas dos solos em regiões tropicais e subtropicais. O objetivo deste trabalho foi avaliar parâmetros de rendimento e morfológicos de soja e de trigo em Latossolo Vermelho sob sistemas de manejo e modelos de produção em região de clima Subtropical (Londrina, Brasil, latitude 23º11'S; longitude 51º11'W; e 620 m de altitude). O delineamento de blocos ao acaso foi usado, em esquema fatorial, com cinco preparos, dois modelos de produção e quatro repetições. Os preparos do solo incluíram o convencional; mínimo escarificado anualmente ou a cada três anos; sistema plantio direto com 11 anos; e sistema plantio direto com 24 anos. O fator sistema de cultivo foi comporto por rotação e sucessão de culturas. Na cultura de soja foi avaliada a produtividade de grãos, massa de mil grãos, altura de plantas e de inserção do primeiro legume, teores de clorofila e índice de vegetação por diferença normalizada, já na cultura de trigo foram avaliadas a produtividade e o pH dos grãos. As produtividades de grãos de soja e de trigo não foram alteradas em função dos modelos de produção. Entre os tempos de adoção do sistema plantio direto não houve diferenças de produção de grãos, sendo maior do que no preparo convencional. A escarificação do solo não incrementou a produtividade de grãos das culturas. Assim, a escarificação do solo sob as condições edafoclimáticas deste estudo é uma prática de manejo dispensável devido à ausência de incrementos morfológicos e produtivos para soja e trigo.

Palavras-chave: sistema plantio direto; experimento de longa duração; *Glycine max*; *Triticum aestivum.*

INTRODUCTION

The use of the no-tillage system aims at the sustainability of the production system since the beginning of its use in the 70s. No-tillage system is based on the application of a set of technologies to avoid soil disturbance, the permanent maintenance of soil surface with crop residue and crop rotation. Intensive agriculture for grain production has reduced the cultural practices of crop rotation in the no-tillage, increasing the areas under crop succession and favouring the formation of a layer with a higher degree of compression between 0.10-0.20 m (FRANCHINI et al., 2011).

The improvement of grain yield in these areas, specially wheat, maize and soybean, over time, demonstrate the existence of a phase of establishment of the no-tillage system, which lasts around six years (FRANCHINI et al., 2012). According to these authors, up to the sixth year of no-tillage implantation, crop productivity tends to be less or equal to that observed in the conventional tillage with plowing and harrowing. In the stabilization phase of the no-tillage, there are increases in soil organic carbon stocks

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(BABUJIA et al., 2010) in such a way that soil quality is improved considerably when compared to the conventional tillage (MORAES et al., 2016). Soil carbon accumulation in the soil favours improvements to physical, chemical and biological processes and attributes of the soil, which are directly and indirectly correlated with plant growth (SILVA et al., 2014).

The lack of clearer results regarding the potential of crop rotation to preserve or improve the soil physical quality in the no-tillage system over time is a barrier to technology adoption by farmers who often opt for mechanical methods of compaction control. Thus, periodic soil chiselling have been used as a common practice in the control of potential problems related to soil compaction and restriction to root growth in some climate conditions, as a Mediterranean conditions, Spain (LÓPEZ-GARRIDO et al., 2014), semi-humid region, China (JIN et al., 2007), cool climate, Denmark (MUNKHOLM et al., 2003), Pampa region, Argentina (BOTTA et al., 2006). But, the most impact effect occur when soil chiselling are used in tropical or subtropical conditions (FRANCHINI et al., 2012; MORAES et al., 2016), specially due to temperature effect for soil carbon decomposition (DAVIDSON; JANSSENS, 2006). Furthermore, the effect tends to decrease over the years as compared with areas cropped to cover crops (CALONEGO; ROSOLEM, 2010), and mechanical chiselling does not promote effective and long lasting improvements in the soil structure (NUNES et al., 2015). However, are necessary consistent long-term experiments of soil tillage systems with soil chiselling in tropical and subtropical climate conditions for evaluate the productive stability of crops, for understanding of the processes involved with the adequate stabilization of the soil structure and response of the crops.

In this work, the following hypotheses were considered: (i) the use of cropping systems based on crop rotation increases the grain yield of the soybean crop; (ii) soybean and wheat grain yields in a subtropical climate condition are not increased due to soil chiselling in relation to continuous no-tillage system, demonstrating that periodic soil chiselling is an unnecessary soil preparation practice; (iii) the increase in the time of no-tillage adoption, in a subtropical climate condition, increases the yield of soybean and wheat grains in relation to the conventional tillage system. The aim of this study was to evaluate the soybean and wheat grain yield and their production components cultivated under different soil tillage systems and production models in a Rhodic Eutrudox, after more than two decades of implantation in a subtropical climate region.

MATERIAL AND METHODS

The experiment was carried out in a long-term experiment establish in 1988 at the Experimental Station of Embrapa Soybean, in Londrina (latitude 23°11'S; longitude 51°11'W; and 620 m altitude), State of Paraná, Southern Brazil. According to the Köppen classification, the climate of the region is humid subtropical (Cfa), with annual average temperature of 21°C and mean maximum and minimum temperatures, respectively, of 28.5°C in February and 13.3°C in July. The average annual precipitation is 1,651 mm, with January being the wettest month (217 mm), and August the driest (60 mm) and extra-terrestrial solar radiation to equivalent evaporation by day of 8.6 mm day^{-1} (June) to 17.1 mm day^{-1} (December) (IAPAR, 2016). The trial was established on an Oxisol (Latossolo Vermelho Distroférrico, Brazilian classification; Rhodic Eutrudox, USA classification) with 710 g clay kg^{-1} soil, 82 g silt kg^{-1} soil and 208 g sand kg^{-1} soil. The soil particle density at 0-0.3 m depth is 2.90 Mg m^{-3}, and the mean slope of the experimental area is 0.03 m m^{-1}. Before the establishment of the experiment, the area had been cropped with coffee (*Coffea arabica* L.) for approximately 40 years, with the entire area receiving similar management and inputs.

The experiment was laid out in a randomized block design, with a 5x2 factorial arrangement (tillage x cropping systems), and four replications. The first factor was five tillage systems: (i) NT24: continuous no-tillage for 24 years, sowing directly through the residue of the previous crop with the opening of only a narrow furrow in the sowing row; (ii) NT11: continuous no-tillage for 11 years; (iii) CT: continuous conventional tillage for 24 years, performed by means of a heavy disk harrow at an average depth of 0.15 m followed by disking with a light disk harrow at 0.08 m depth, preceding the summer and winter crops; (iv) MTC1: minimum tillage, with annual chiselling before the winter crop; and (v) MTC3: minimum tillage, with chiselling before the winter crops every three years. Between 1988 and 2001, the soil in NT11 was tilled with mouldboard plough (average working depth of 0.32 m) and light disk harrow (0.08 m depth) before planting the summer crop, and heavy disk harrow (average working depth of 0.15 m) followed by light disking before planting the winter crop. The MTC1 and MTC3 plots were chiselled before planting the winter crops, using a mounted chisel plough with roller combination, and four shanks spaced 0.40 m apart, working at an average depth of 0.30 m.

The second factor was two cropping systems, than included: (i) wheat (*Triticum aestivum* L.) in the winter and soybeans (*Glycine max* (L.) Merr) in the summer, repeated each year, designated as crop succession (CS); and (ii) a 4-year crop rotation (CR), with the following species in winter-summer: white lupine (*Lupinus albus* L.) – maize (*Zea mays* L.); black oats (*Avena strigosa* Schreb.) – soybean; wheat – soybean; wheat – soybean. The 6th crop rotation cycle was ended in the 2012/2013 crop season. Plots measured 10 m in width and 30 m in length, and were spaced 7 m from each other to enable tractor turning during operations. The average dry biomass production of the crops in CS and CR was approximately 5.3 and 7 Mg ha^{-1} yr^{-1}, respectively. The average soil organic carbon content at 0.0-0.10 m depth was 18.9, 19.9, 19.8, 20.6, and 21.9 g kg^{-1} in CT, MTC1, MTC3, NT11, and NT24, respectively (MORAES et al., 2016).

The temperature and precipitation data were collected at the Embrapa soybean weather station, from October 2011 to September 2012. The water balance was carried out to determine the inputs and outputs of water in the soil,

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using the methodology proposed by Thornthwaite e Mather (1955), serial per ten-days (CUNHA, 1992). For the calculation of the water balance, it was used a Microsoft Excel™ worksheet (ROLIM; SENTELHAS; BARBIERI, 1998) in which mean temperature and total precipitation data, site latitude and available water capacity (AWC) in the soil are entered. In this work, the available water capacity used was 75 mm.

In the summer crop of 2011/12, soybean (cultivar BRS 316RR) was grown and, and wheat (cultivar BRS Tangará) was cultivated in the winter of 2012. In each year, all plots received the same amounts of fertilizers (N, P_2O_5 and K_2O) based on the specific recommendations for each crop (EMBRAPA, 2011). Crop managements for pest and disease were the same in all treatments. The grain yield of the soybean was determined by the mechanical harvesting of 25 m of the eight central lines, spaced in 0.45 m, of each plot, using a self-propelled SLC-6200 harvester. The grain yield of wheat was determined by the mechanical harvest of 25 m in the 20 central lines in each plot, spaced in 0.17 m. The grains of both crops were cleaned and weighed, and the values obtained were corrected to a moisture content of 13%. In wheat grains was determined the hectolitre weight. Hectolitre weight is defined by the weight of a measured volume of grain expressed as kilograms per hectolitre (kg/hl) and reflects the bulk density of grain. At the time of the soybean harvest, the following crop characteristics were evaluated: plant height, given by the distance from the plant collar to the end of the main stem, in cm, measured in five plants at random; Height of insertion of the first legume, given by the distance from the neck of the plant to the lower extremity of the first legume, in cm, of five plants taken at random; Mass of one thousand grains, determined according to the methodologies described in the Rules for Seed Analysis (BRASIL, 2009).

In the phenological stage R5.3 of soybean, in the 10th (1st reading) and 15th (2nd reading) of December 2012, the normalized difference vegetation index (NDVI) was determined using the *GreenSeeker® 505 Handheld Sensor*, according to methodology described in GROHS et al. (2009). NDVI data were collected dynamically at a height of 80 to 120 cm from the vegetative canopy, at a distance of 5 meters in the centre of the plots, wherein the sensor performs scanning readings. The NDVI is related to the photosynthetically active foliar biomass per unit of area, the higher this vegetation index, the denser the green phytomass. At the same time, the relative levels of chlorophyll in the leaves were determined using SPAD index (SPAD-502® Chlorophyll meter), a factor that is related to the leaf area of the plants where the photosynthetic pigments are present. The SPAD index readings were performed in six plants of each plot on the central trifolium of the third expanded leaf of the soybean and converted to the chlorophyll content by equation 1.

$$\text{Chlorophyll content} = \text{SPAD x } 0.0007 - 0.0071 \qquad \text{(Eq. 1)}$$

The results were submitted to analysis of variance (Test F, p <0.05). When the effects of the treatments were significant, the averages were compared by the Tukey test at the 5% level of error probability. The analyses were performed using the software Statistical Analysis System (SAS Institute).

RESULTS AND DISCUSSION

Analysis of variance for productive and morphological parameters of soybean and wheat did not shown interactions of factors tillage and cropping systems. In this way, averages were compared for each factor (tillage and cropping system) in an isolated way.

The plant height and the insertion height of the 1st legume were not influenced by the production models (Figures 1a and 1b). The two production models provided adequate environment for the growth of soybean plants (Figure 1a). It is observed that the plants obtained height of 0.85 m, with insertion of the first legume at 0.20 m height in succession and about 0.19 m in rotation. Thus, the plant heights and the insertion of the first legume were adequate, because according to recommendations the obtaining of plants with plant height (between 60 and 120 cm) of insertion of the first legume (greater than 10 or 15 cm) compatible with the mechanized harvest is an important factor of production (CARVALHO et al., 2010).

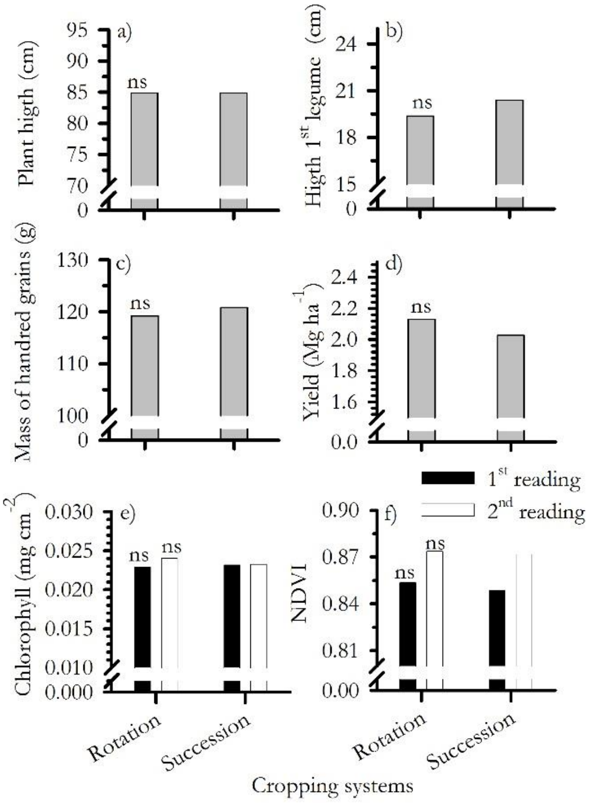

Figure 1. Soybean morphological parameters due cropping systems in a Rhodic Eutrudox: plant height (a); insertion height of first legume (b); mass of a thousand grains (c); soybean grain yield (d); chlorophyll content (e); and normalized difference vegetation index (NDVI) (f). ns not significant.

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The grain mass (Figure 1c) and grain yield (Figure 1d) of soybean, levels of chlorophyll (Figure 1e) and NDVI (Figure 1f), were not influenced by crop rotation and succession models. The differences between the two production models were not enough to characterize grain yield increases in the crop rotation model. However, it should be noted that this evaluation was carried out in the third year of the crop rotation cycle (lupine / maize-oats / soybean-wheat / soybean-wheat / soybean), where the crops used for crop rotation are equal to the succession of crops, and the residual effects are reduced in relation to the first years after the use of rotation crops. Soybean crop presents positive responses to crop rotation, particularly when grown in the summer following summer maize cultivation (FRANCHINI et al., 2012). These authors observed a 17% increase in the average yield of soybean, under rotation system with maize, in relation to that observed in the succession with wheat. Santos et al. (2006) reported that the higher grain yields in crop rotation systems relative to the wheat / soybean succession model were related, in part, to the final population of plants, the grain mass per plant, the mass of thousand grains and the height of soybean plants.

Soil tillage systems significantly altered plant height, a thousand grain mass and grain yield, and did not influence the insertion height of the first legume (Figure 2). The height of soybean plants in MTC3 was higher than that observed in CT, without differing from other treatments (Figure 2a). There were no differences in plant height as a function of the adoption time of no-tillage (NT11 and NT24). Thus, the use of soil chiselling has not proved to be an efficient practice to improve the environment for growth and development of soybean plants.

The mass of one thousand grains and the grain yield of the soybean were altered according to the tillage systems (Figures 2c and 2d). NT24 and NT11 resulted in a greater mass of a thousand grains in relation to CT, which did not differ from other treatments. There were no differences in grain yield and mass of a thousand grains of soybeans between the times of NT adoption. There was a significant reduction in soybean grain yield in CT compared to NT24. The reduction of grain yield of the crops in CT is probably related to soil physical conditions in this preparation system, reported in Moraes et al. (2016), which attributed to the intense soil rotation in the CT the degradation of the soil physical and chemical attributes. This practice negatively affected soil structure, pore continuity, and soil carbon content.

On the other hand, there were no differences in grain yield and one thousand grain mass between soil tillage MTC1 and MTC3 in relation to the other treatments. Therefore, the practice of sporadic soil chiselling is not necessary, since, besides breaking the structure of the stable aggregates of the soil, it does not favour increments of soybean grain yield in relation to the tillage systems without soil disturbance, much less in relation to the CT. Thus, soil chiselling does not always result in benefits to the development of crops. For example, Franchini et al. (2011) prove than only one of the 21 harvests evaluated, periodic soil chiselling used every three years, associated with crop rotation, significantly increased soybean yields in relation to continuous NT. These same authors observed reductions up to 600 kg ha^{-1} when soil chiselling was used, along with succession of crops.

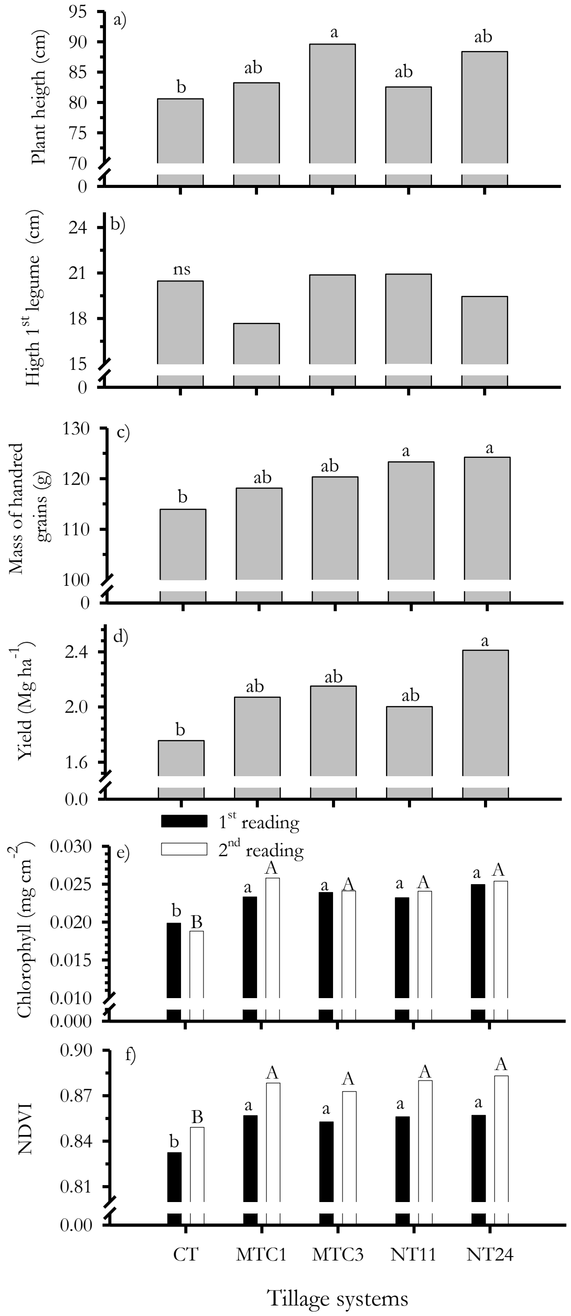

Figure 2. Soybean morphological parameters due tillage systems in a Rhodic Eutrudox: plant height (a); insertion height of first legume (b); mass of a thousand grains (c); soybean grain yield (d); chlorophyll content (e); and normalized difference vegetation index (NDVI) (f). ns not significant; *means followed by the same letter in the same layer did not differ by Tukey's test ($p<0.05$). CT: conventional tillage; MTC1: minimum tillage with soil chiselling every year; MTC3: minimum tillage with soil chiselling every three years; NT11: continuous no-tillage for 11 years; NT24: and continuous no-tillage for 24 years.

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The chlorophyll and NDVI contents of the soybean crop, in both evaluations at the R5.3 stage, indicated that there was an effect of soil management (Figures 2e and 2f). The lowest levels of chlorophyll and NDVI were observed in the CT, indicating worse conditions for the development of the culture in this preparation system. NDVI is an important parameter due to higher relationship of this parameter with grain yield, this was observed early for soybean crop (ARAÚJO; VETTORAZZI; MOLIN, 2005).

Throughout the soybean development cycle in the 2011/12 crop, it was observed, through the water balance, that there were several periods with water deficiency (Figure 3). The total water requirement in the soybean crop is around 411 mm per cycle (MOREIRA et al., 2015); however, the daily water requirement may increase as the plant develops, reaching the maximum during flowering and grain filling (7 to 8 mm / day), decreasing after this period (EMBRAPA, 2011), Rainfall distribution throughout the soybean cycle was a medium of 3.66 mm day^{-1}. Thus, if that would be well distributed during the soybean season growth, this water depth is enough; however, at the phenological stage of soybean flowering, there was a short period with water deficit, where potential evapotranspiration values exceeded the accumulated rainfall balance.

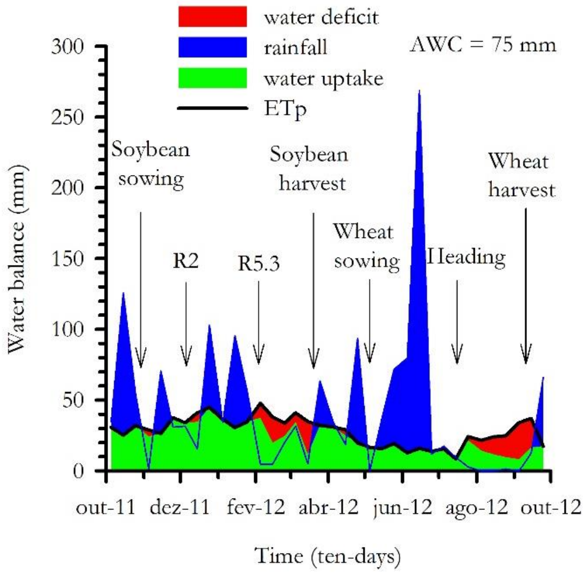

Figure 3. Soil-water-balance during season growth of soybean and wheat crop. AWC: availability water capacity; ETp: Potential evapotranspiration.

Since 20th December to the end of January, there was regularization in the rainfall indexes, so that the water demand of the crop was adequately provided. There was a long period of water deficiency in the phenological state of grain filling (R5.3), which lasted until the end of the soybean season growth. It is important for evaluate the water availability from tillage system to crop growth. Thus, storage of soil water, over a long period, was below the need, damaging the filling of grains of the soybean and, thus, reducing the productivity of the crop in conventional system and chiselled soil. In this region under study, rainfall in the period from December 2011 to March 2012 was lower than the average for the period 1976 to 2011, characterizing it as a period of water deficit (IAPAR, 2016). However, the yield of soybean and wheat grains were similar to the average grain yield of the 2011/12 harvest in the State of Paraná (2,429 kg ha^{-1}), and the adverse climatic conditions caused by the phenomenon "La Niña" were responsible for the negative result of the harvest (CONAB, 2012).

Soybean grain yield was linearly positive related with a thousand grain mass and plant height (Figure 4a, b). There was a 60% correlation between the increase in grain yield of soybean with the increase of the mass of a thousand grains and or the height of plants. As expected, this correlation demonstrates the importance of the mass of a thousand grains in the production, especially in periods with water deficiency, such as occurred during the filling of soybean grains. This demonstrates the importance of no-tillage in increasing soybean tolerance to hydric stresses (FRANCHINI et al., 2009), increasing the bond number and strength of soil aggregates by age-hardening phenomena (MORAES et al., 2017), improving soil aggregation and its structure that allows greater storage of available water (SILVA et al., 2014), upward flow of water from the deeper layers to the more superficial layers of water (MORAES et al., 2016) and increased rooting depth (MORAES, 2017). Santos et al. (2006) observed that, independently of crop rotation systems, soybean cultivated under no-tillage showed higher grain yields, a greater mass of 1,000 grains, with higher plant height than soybean cultivated under conventional tillage system, with disk plow or turning plow.

Thus, this demonstrating than those three variables are related to each other and those morphological parameters may indicate reductions in grain yield of soybeans. However, it is important to note that 40% of the grain yield results had no correlation with mass of a thousand grain or plant height, demonstrating that there are other factors linked to soybean grain yield. This indicated soybean response is related to environmental, and it is not only dependent to genetic characteristic. For this reason is important to understand the direct factors that affect plant development. The soil physics factors that affect direct the crop response are water, aeration, temperature and mechanical impedance (LETEY, 1985).

There was no relationship between grain yield and height of the first soybeans (Figure 4c). The height of insertion of the first legume can be related indirectly to productivity, because if this insertion was below 0.10 m, there may be losses at the moment of mechanized harvesting of the plants (CARVALHO et al., 2010).

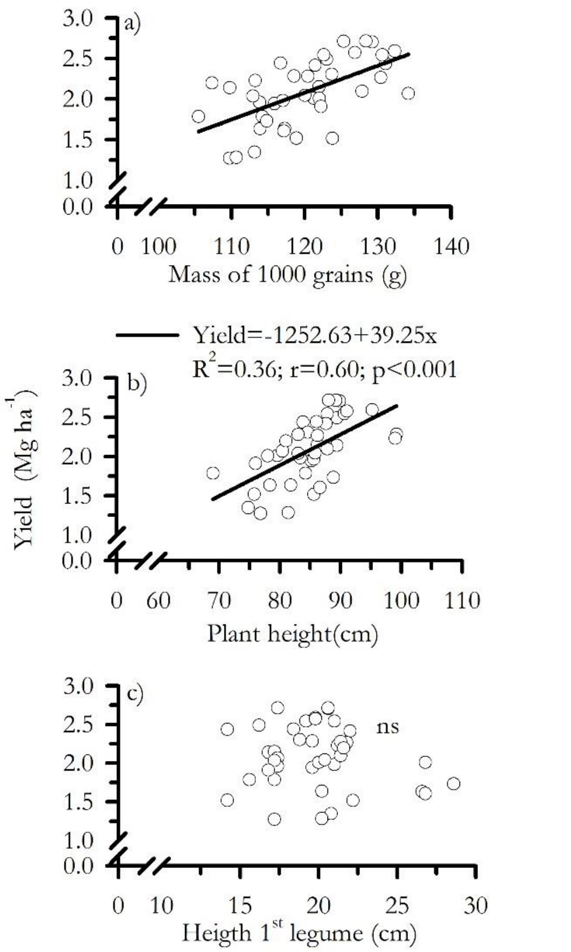

Figure 4. Relationship of grain yield and mass of a thousand grains (a), plant height (b), and insertion height of first legume of soybean. **ns not significant.**

In the period from May to June 2012, precipitation accumulations were much higher than potential evapotranspiration, demonstrating that adequate water availability was enough for the growth and development of the wheat crop (Figure 3). In July 2012, there was a reduction in precipitated volumes, initiating a long period of hydric stress. This period of water deficit coincided with the stage of higher water requirement of the crop (grain filling) (LIBARDI; COSTA, 1997), resulting in reduced wheat yield. The effect of drought on crop productivity depends on the intensity, duration, time of occurrence and interaction of water deficiency with other determinants of productivity potential expression (WILHITE; SIVAKUMAR; PULWARTY, 2014).

Hectolitre weight and grain yield of wheat were not influenced by the cropping systems (Figure 5). There were no differences in hectolitre weight regarding on the models based on crop rotation and succession (Figure 5a). However, use of succession of wheat/soybean have been reduced hectolitre weight when compared to crop rotation systems, and this reduction of hectolitre weight may be related to the higher incidence of diseases in the root system (GUARIENTI; SANTOS; LHAMBY, 2000). It is important to note that, in the year of evaluation, wheat cultivation was in its fourth year after the beginning of the sixth cycle of the crop rotation scheme (lupine-maize / soybean-oats / wheat-soybean / wheat-soybean). Wheat grain yield differences between crop rotation and crop rotation systems are being reduced as the crop is repeated in the area after each winter (FRANCHINI et al., 2012). In this sense, the highest grain yield gains of the wheat crop, in relation to the wheat / soybean succession, are obtained in the first wheat crop within each rotation cycle.

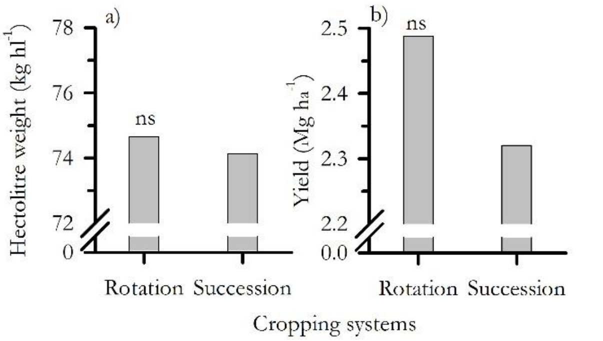

Figure 5. Wheat hectolitre weight (a) and grain yield (b) due cropping systems in a Rhodic Eutrudox. **ns not significant.**

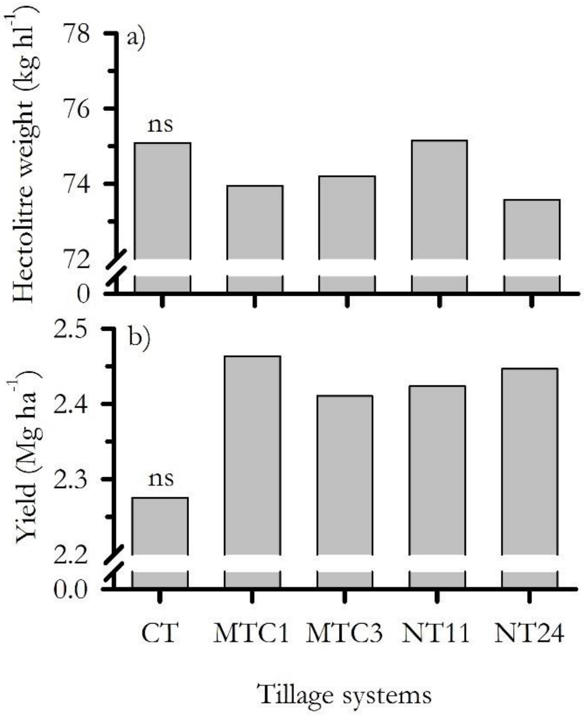

Figure 6. Wheat hectolitre weight (a) and grain yield (b) due tillage systems in a Rhodic Eutrudox. **ns not significant. CT: conventional tillage; MTC1: minimum tillage with soil chiselling every year; MTC3: minimum tillage with soil chiselling every three years; NT11: continuous no-tillage for 11 years; NT24: and continuous no-tillage for 24 years.**

Soil tillage systems did not change the hectolitre weight and grain yield of wheat crop (Figure 6). The use of soil chiselling annually or every three years did not prove to be an efficient practice to increase wheat grain yield compared to NT11 and NT24. Therefore, continuous no-tillage

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system without soil revolving has the potential to maintain a favourable environment for wheat cultivation without the need for mechanical interventions, independently of the cropping system. Thus, soil chiselling is unnecessary, increasing production costs for wheat cultivation without increments in grain yield or wheat hectolitre weight. The absence of positive crop response due soil chiselling, usually occur due reduction of soil water availability (MORAES et al., 2016), reduction of soil retention during crop growth (CALONEGO; ROSOLEM, 2010), consequently increasing the stresses days to grain production (FRANCHINI et al., 2012), furthermore, mechanical soil chiselling have effect only for a short time (NUNES et al., 2015). Thus, the best condition to crop response is no-tillage over time.

CONCLUSIONS

Soil chiselling in a Rhodic Eutrudox is an unnecessary practice and does not increase the yield of soybean and wheat grains in relation to the continuous no-tillage system, regardless of the cropping system adopted.

No-tillage system older increase soybean grain yield in relation to conventional tillage systems in a Rhodic Eutrudox.

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