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Effects of different soil tillage systems and coverages on soybean crop in the Botucatu Region in Brazil

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Abstract

Nowadays, agricultural practices should combine high yields with a sustainable use of resources. Different tillage practices and crop covers, if combined, may help to achieve both objectives. In this work, several traits of a soybean (*Glycine max* L. Merr) cultivar were studied under different conditions of tillage and previous soil coverages. The experiment was installed at Lageado Research Station, Botucatu county, SP, Brazil, on a Paleudult. It consisted of nine treatments (combining three systems of soil tillage and three cover crops) and 4 replicates, yielding 36 plots of a randomized block experimental design. The soil tillage systems considered were: (i) conventional tillage with two heavy harrowing and a levelling harrowing; (ii) chiseling, and (iii) no-tillage with chemical drying of vegetation. The three cover crops used were: black oat, sorghum and spontaneous vegetation. Analyzed variables were: plant height, initial and final plant densities, height of first pod insertion, weight of a thousand grains, number of pods per plant, number of grains per pod, and crop yield. No significant differences were observed for most of the analyzed variables; however, conventional tillage produced significantly heavier grains and a higher number of pods per plant. The selected covers were considered an excellent coverage prior to planting soybean in a crop rotation. The three tillage systems can be used for deployment of culture without compromising the development of soybean.

Additional key words: black oat, chisel, *Glycine max*, heavy harrow, sorghum, yield.

Resumen

Efectos de diferentes sistemas de laboreo del suelo y coberturas vegetales sobre la cosecha de soja en la región de Botucatu en Brasil

Actualmente, las prácticas agrícolas deben combinar elevadas productividades con un uso sostenible de los recursos. Diferentes sistemas de laboreo y coberturas vegetales, combinados, pueden ayudar a conseguir ambos objetivos. En este trabajo se han estudiado diversos aspectos de un cultivar de soja (*Glycine max* L. Merr) sometido a diferentes condiciones de laboreo y cobertura vegetal. El experimento se llevó a cabo en la Estación Experimental de Lageado, Botucatu (São Paulo, Brasil) sobre un Paleudult, y constó de nueve tratamientos (tres sistemas de laboreo y tres coberturas vegetales combinados) y cuatro repeticiones, totalizando 36 parcelas con un diseño experimental en bloques aleatorios. Los sistemas de laboreo considerados fueron (i) laboreo convencional con dos gradas pesadas y una niveladora; (ii) escarificado y (iii) no laboreo con desecación química de la vegetación. Las tres coberturas utilizadas fueron la avena negra, el sorgo y la vegetación espontánea. Las variables analizadas fueron altura de las plantas, densidad inicial y final de plantas, altura de la inserción de la primera vaina, peso de mil granos, número de vainas por planta y de granos por vaina y productividad de la cosecha. No se observaron diferencias significativas en la mayoría de las variables; sin embargo, el laboreo convencional produjo granos significativamente más pesados y un mayor número de vainas por planta. Las coberturas seleccionadas se consideraron excelentes previas a la plantación de soja en una rotación de cultivos. Los tres sistemas de laboreo pueden implementar el cultivo sin comprometer el desarrollo de la soja.

Palabras clave adicionales: avena negra, escarificadora, *Glycine max*, grada pesada, producción, sorgo.

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Abbreviations used: CT (conventional tillage), masl (meters above sea level), NT (no tillage), RT (reduced tillage), UNESP (Universidade Estadual Paulista "Júlio Mesquita Filho").

Introduction

Development and improvement of new technologies is one of the challenges in current research on agriculture. This development is mainly related to agricultural machines in order to evaluate or increase their efficiency under different conditions (Camacho-Tamayo and Rodríguez, 2007; Serrano and Peça, 2008; Serrano *et al.*, 2008). Furthermore, as pointed out by Barrios *et al.* (2006), agricultural scientists are searching for new ways to enhance crop production, reduce costs, and improve soil and water conservation while reducing the environmental impact of agriculture.

Soil tillage systems are important factors in the conservation of soil physical, chemical, and biological properties since they are able to control, or even reduce, erosion and losses by runoff (Bertol *et al.*, 2004). Conventional tillage favors water erosion processes because it promotes an excessive mobilization of topsoil. On the contrary, conservation managements reduce the mobilization of the soil and, therefore, maintain vegetal residues on the topsoil improving the environment for plant growth (Negi *et al.*, 1990).

Conversely, a number of authors (Dickey *et al.*, 1984; Lopes *et al.*, 1987; Amado *et al.*, 1989; Carvalho *et al.*, 1990; McGregor *et al.*, 1990, Schick *et al.*, 2000, Salako *et al.*, 2007) have described the benefits that crop covers provide to the soil when remaining on soil surface. These coverages decrease water and soil losses mainly because of the protection they provide against the detachment caused by raindrops; moreover, they constitute a physical barrier to runoff.

In addition, vegetal residues, incorporated or not to soil surface, contribute to control invasive plants since they exert a suppresive effect on the growth of these plants. An appropriate cover can prevent erosion, maintain the organic matter content and allow culture sustainability. Derpsch *et al.* (1986) recommended a conservation management, such as no tillage, and a straw cover in order to save time, fuel and work.

Nevertheless, recent studies (Bertol *et al.*, 2007) proved that some conservation systems increase the losses of certain nutrients, such as phosphorus, from soils. It has been seen that the main factors controlling sustainability of resources are tillage systems, cultured crops, machinery and soil coverage by residues. More studies that consider all these characteristics are needed in order to enhance our knowledge in agricultural sustainability.

Although different characteristics of soybean have been previously studied in this or in a similar framework (Santos *et al.*, 1994a; Barrios *et al.*, 2006; Di Ciocco *et al.*, 2008), reported results differed considerably depending on the considered trait. This fact may reflect a lack of suitability in certain culture traits in order to describe the effects of management techniques and coverages.

Following these premises, the aim of the present study was to determine the influence of different tillages systems and cover crops on several traits of a soybean cultivar and the yield of this crop. Finally, considerations on the suitability of the studied characteristics for describing the variability regarding tillage system and cover crop are discussed.

Material and methods

This experiment was performed in the agricultural year 2004-2005 at the "Lageado" Research Station, located at the Agronomic Sciences Faculty of UNESP, Campus Botucatu (22º 49' S, 48º 25' W, 770 masl, mean slope 0.045 m m^{-1} exposed to North) in São Paulo, Brazil. This area has been cultivated using the same treatments as the ones later described for this study since 2000.

Soils at the site were classified a Paleudult [Soil Survey Staff, 2006]. Textural analysis showed that the soil presented 113 g kg^{-1} sand, 296 g kg^{-1} silt and 591 g kg^{-1} clay in the 0 to 20 cm layer. Fertilization was carried out considering a soil chemical analysis: 5.5 pH in $CaCl_2$, 41 mg dm^{-3} P, 4.1 $mmol_c$ dm^{-3} K^+, 51 $mmol_c$ dm^{-3} Ca^{+2}, 23 $mmol_c$ dm^{-3} Mg^{+2}, 34 $mmol_c$ dm^{-3} H^+ + Al^{+3}, 0.0 $mmol_c$ dm^{-3} Al^{+3}, 3 mg dm^{-3} S, 0.33 mg dm^{-3} B, 2.8 mg dm^{-3} Zn^{+2}, and 70% of base saturation.

The experimental design was in randomised blocks with four replications for each treatment. The treatments were three tillage systems: conventional tillage (CT), reduced tillage (RT) and no tillage (NT). Moreover, three cover crops were established: black oat (*Avena strigosa*), sorghum (*Sorghum vulgare* L.) and spontaneous vegetation. Thus, a total of nine treatments (each a combination of a tillage system and a vegetal cover) were established. Each experimental plot measured 150 m^2 (7.5 x 20 m, width and length, respectively).

Conventional tillage was undertaken using a heavy-disc harrow composed by 81.28 cm discs followed by passes with a light-disc harrow with 60.96 cm discs. For reduced tillage, a chisel plow was used with a rototiller wich consisted of seven parabolic tines, each peak was 80 mm long. Regarding vegetal covers, black oat (*Avena strigosa*) with 85% germinative capacity was sown using a planter with a continuous flux and a distribution of 80 kg ha^{-1}, and 170 mm spacing. In the case of sorghum, a grain drill (model PST[2], Tatu Marchesan) was used, distributing 12 seeds by meter each line, its germinative capacity was 91% and the spacing 450 mm.

Soybean cultivar IAC 19, with a germinative capacity of 92% and a purity of 88% was sown at a density of 21 seeds per meter in each row. Fertilization was provided as 300 kg ha^{-1} of 04-30-20 N, P_2O_5, K_2O, respectively. A grain drill (model PST[2], Tatu Marchesan) was used for sowing the soybean; this planter had 6 sowing lines spaced 450 mm and it was connected to a John Deere 6600 tractor with 89 kW (121 hp) which was the same engine used in all the tillage operations. For the agrochemical applications, a condor-400 bar sprayer (400 L capacity) was utilised, it was connected to a MF 235 (Massey Ferguson) tractor which had a power of 27 kW (37 hp).

The observed soybean traits were: plant height, initial and final plant density, height of the first-pod insertion, thousand-grain weight, number of pods per plant, number of grains per pod, and crop yield. These traits were determined at harvest except the plant density which was also measured at the beginning of the experiment, specifically, 7 days after full emergence.

In the case of plant height, number of pods per plant, and number of grains per pod variables, 10 plants were randomly collected at each plot. Plant height was considered as the distance from the soil to the apical meristem of the main stem. First-pod insertion was accounted for as the distance from the main stem to the first-pod insertion. Number of pods per plant was assessed from the plants used in the determination of plant height and first-pod insertion. Then, pods were counted and the average per plant was calculated. For the variables thousand-grain weight, crop yield, and initial and final density of plants, 4.5 m^2 (two sowing rows and 5 m length) subplots in each plot were considered. These measurements were made in laboratory conditions after drying the plants or the grains into a stove.

Analyses of data were carried out using SISVAR software (Ferreira, 2000). Analysis of variance was done in order to separate means for the various treatments. Least significant differences were reported at $P < 0.05$. Tukey test at 5% of significance was used for mean comparison.

Results

During the growth of the soybean crop (December 2004 to April 2005), precipitation was normal for the region. Total monthly rainfall varied from 65.6 mm in February 2005 to 424.4 mm in January 2005.

No significant differences were observed on plant height among the different treatments studied (Table 1). However, slightly higher values were observed under CT except in the case that soybean was preceded by spontaneous vegetation when it presented the lowest plant height for the three tillage systems. Minimum average value was observed for the combination of RT after sorghum cover with a value of 70.05 cm (Table 1). Moreover, RT showed the lowest plant height value for the average of the three coverages.

Plant density average data are presented in Tables 1 and 2. No significant differences were observed among treatments for this characteristic either the initial or the final density. In the case of initial plant density, values were very similar among tillage systems and coverages. However, initial plant density was always higher than final plant density. In addition, the maximum plant density average value, either initial or final, was observed for the combination of NT after black oat cover (Tables 1 and 2).

Regarding the height of the first-pod insertion (Table 2), higher values were observed under CT and NT. Likewise, spontaneous vegetation cover presented the higher mean values for this variable. Nevertheless, these differences proved to be non-significant except in the case of the average values for each coverage; in this case, soybean grown after a black oat coverage showed the lowest values for this trait.

Weight of a thousand grain proved to be significantly higher in CT and NT, 152 and 138.22 g, respectively, than in RT, 134.5 g (Table 3). The lowest average values for this trait were observed after coverage of sorghum. Although no-significant differences were observed accounting for soil coverage, soybean grown after black oat cover presented the highest average value for this trait, 148.53 g, while the lowest was observed after sorghum cover (137.7 g).

Number of pods per plant proved to be a variable highly dependent on the treatment since significant differences were observed among almost all the combinations of tillage systems and cover crops (Table 3). In this case, CT and RT showed higher average values for this trait than NT. The highest values were observed after black oat cover (75.5, 74.9 and 65.25 pods per plant for

Table 1. Plant height and initial plant density average values for soybean cv. IAC 19 as a function of tillage systems and cover crops

Cover crops	Soil tillage systems			Averages
	Conventional	Reduced	No tillage	
Plant height (cm)				
Black oat	77.05 (± 7.73) aA	70.95 (± 7.27) aA	73.85 (± 9.60) aA	73.95 a
Sorghum	76.55 (± 7.61) aA	70.05 (± 6.17) aA	71.25 (±-6.80) aA	72.62 a
Spontaneous vegetation	75.50 (± 11.76) aA	77.50 (± 5.77) aA	76.90 (± 5.77) aA	76.60 a
Averages	76.37 A	72.83 A	74.00 A	
Initial plant density (plants m^{-1})				
Black oat	15.44 (± 1.29) bB	14.98 (± 1.41) bB	15.68 (± 0.58) bB	15.36 b
Sorghum	14.98 (± 1.41) bB	14.98 (± 1.15) bB	15.21 (±1.29) bB	15.05 b
Spontaneous vegetation	15.44 (± 0.50) bB	15.44 (± 0.50) bB	15.21 (±1.50) bB	15.36 b
Averages	15.28 B	15.13 B	15.36 B	

Means followed by the same letter (small in columns and capital in rows) are non-significant according to Tukey test, p = 5%.

CT, RT and NT, respectively) and the lowest ones after spontaneous vegetation (65.45, 65.77 and 64.32 pods per plant for CT, RT and NT, respectively).

Number of grains per pod was another treatment-sensitive variable (Table 4). Higher values for this trait were observed under CT and RT than under NT. After black oat coverage, soybean produced the highest average values for this feature (2.86 grains per pod), whereas after sorghum and spontaneous vegetation, it presented the same average value (2.49 grains per pod).

In addition, soybean crop yield (Table 4) did not present significant differences among treatments. However, CT yielded the highest value, 1488 kg ha^{-1}, while NT produced the lowest one, 1315 kg ha^{-1}. Accounting for covers, soybean grown after black oat yielded 1451 kg ha^{-1}, the highest value against 1359 and 1375 kg ha^{-1} after sorghum and spontaneous vegetation, respectively.

ANOVA analysis identified significant interaction effects between soil tillage systems and plant covers only for two of the studied variables: number of pods per plant (p-value = 0.02) and number of grains per pod (p-value = 0.02). For the rest of the variables, no interaction effect was detected: plant height (p-value = 0.64), initial plant density (p-value = 0.77), final plant density (p-value = 0.76), height of the first-pod insertion (p-value = 0.9), thousand-grain weight (p-vaue = 0.7) and crop yield (p-value = 0.62).

Table 2. Final plant density and height of the first-pod insertion average values for soybean cv. IAC 19 as a function of tillage systems and cover crops

Cover crops	Soil tillage systems			Averages
	Conventional	Reduced	No tillage	
Final plant density (plants m^{-1})				
Black oat	13.25 (± 0.96) aA	13.03 (± 0.82) aA	13.54 (± 0.58) aA	13.25 a
Sorghum	13.03 (± 0.82) aA	12.96 (± 1.41) aA	12.74 (± 1.26) aA	12.88 a
Spontaneous vegetation	13.25 (± 0.96) aA	12.74 (± 0.96) aA	12.46 (± 1.00) aA	12.81 a
Averages	13.18 A	12.88 A	12.88 A	
Height of the first-pod insertion (cm)				
Black oat	12.43 (± 2.49) bB	10.98 (± 3.77) bB	10.85 (± 2.24) bB	11.42 b
Sorghum	13.83 (± 3.51) cC	11.83 (± 2.33) bB	15.10 (± 1.78) cC	13.58 c
Spontaneous vegetation	15.20 (± 3.55) cC	13.83 (± 1.83) cC	14.68 (± 2.82) cC	14.57 c
Averages	13.82 C	12.21 B	13.54 C	

Means followed by the same letter (small in columns and capital in rows) are non-significant according to Tukey test, p = 5%.

Table 3. Thousand-grain weight and number of pods per plant average values for soybean cv. IAC 19 as a function of tillage systems and cover crops

Cover crops	Soil tillage systems			Averages
	Conventional	Reduced	No tillage	
Thousand-grain weight (g)				
Black oat	152.22 (± 26.88) aA	145.98 (± 9.48) aA	147.38 (± 17.68) aA	148.53 a
Sorghum	148.13 (± 11.14) aA	128.08 (± 11.77) bB	136.90 (± 9.27) aA bB	137.70 ab
Spontaneous vegetation	155.65 (± 16.31) aA	129.45 (± 12.71) bB	130.38 (± 25.32) aA bB	138.49 ab
Averages	152.00 A	134.50 B	138.22 AB	
Number of pods per plant				
Black oat	75.50 (± 2.08) cC	74.99 (± 2.94) cC	65.25 (± 2.22) cC D	70.73 c
Sorghum	69.89 (± 6.22) cC d	66.26 (± 1.50) Cd	63.20 (± 1.50) cC	66.42 d
Spontaneous vegetation	65.45 (± 2.52) Cd	65.77 (± 4.11) Cd	64.32 (± 6.35) cC	65.29 d
Averages	70.22 C	68.89 C	63.20 D	

Means followed by the same letter (small in columns and capital in rows) are non-significant according to Tukey test, p = 5%.

Discussion

Plant height results were in accordance with those found by Santos *et al.* (1994a) who evaluated several agronomic characteristics of soybean culture under different soil tillage systems at Roraima (Brazil). They detected no significant differences in relation to plant height. However, they observed lower growths in soybean plants under no tillage conditions than those in conventionally tilled fields. In contrast, Lopes *et al.* (2007) reported significant differences between NT and CT conditions in soybean plant height, being significantly higher those plants grown under NT. The results from the current study reported no significant differences among treatments, however, slightly lower plant heights were measured under NT than under CT conditions.

Santos (1991) compared initial and final soybean plant density under different conditions of tillage and crop cover, this author observed that NT presented the highest number of plants and this value was significantly higher to that observed under RT conditions. Anaele and Bishnoi (1992) observed the opposite effect which was explained by a better contact between soil and soybean seeds provided by CT. In the current work, the fact that no-significant differences were observed on plant

Table 4. Number of grains per pod and crop yield average values for soybean cv. IAC 19 as a function of tillage systems and cover crops

Cover crops	Soil tillage systems			Averages
	Conventional	Reduced	No tillage	
Number of grains per pod				
Black oat	3.24 (± 0.29) aA	3.28 (± 0.21) aA	2.19 (± 0.16) aB	2.86 a
Sorghum	2.69 (± 0.36) bA	2.53 (± 0.05) bA	2.28 (± 0.10) aA	2.49 b
Spontaneous vegetation	2.37 (± 0.10) bA	2.50 (± 0.38) bA	2.37 (± 0.43) aA	2.49 b
Averages	2.76 A	2.72 A	2.28 B	
Crop yield (kg ha^{-1})				
Black oat	1470 (± 309.05) cC	1507 (± 149.29) cC	1375 (± 203.80) cC	1451 c
Sorghum	1463 (± 97.25) cC	1276 (± 117.20) cC	1338 (± 193.23) cC	1359 c
Spontaneous vegetation	1530 (± 157.47) cC	1363 (± 66.04) cC	1232 (± 298.30) cC	1375 c
Averages	1488 C	1382 C	1315 C	

Means followed by the same letter (small in columns and capital in rows) are non-significant according to Tukey test, p = 5%.

density, both initial and final, for the studied treatments may be explained because the climatic conditions did not compromise soybean emergence or establishment since no water stress was observed during the cycle of the culture.

First-pod insertion values were significantly higher after covering the soil with sorghum or with spontaneous vegetation than when it was covered with black oat. In case that first-pod insertion is located higher in the plant, more grain losses caused by wind and other mechanical factors are expected, as pointed out by Mesquita *et al.* (2002), this fact may reduce the final yield of the crop.

Results for weight of a thousand grains observed in this study were of the same order of magnitude than those reported by Lopes *et al.* (2007). This variable proved to be sensitive to tillage; however, it showed no significant differences regarding soil coverage. This is contrasting with the findings of Lopes *et al.* (2007) who detected differences with the covers and not with the tillage. Probably, these differences were caused by the fact that the covers they considered were different from those accounted for in the present study.

Santos and Reis (1994) reported no significant differences in the number of pods per plant regarding soil management. These results are different from those observed in the current study which may be caused by the fact that the crop covers analysed by this author differed from those accounted in this work. In addition, since this variable was affected by an interaction of soil system and plant cover, a plausible explanation for this result is that the effect of this interaction was the cause of the significant differences between treatments and they were not only caused by one factor.

Moreover, reported results by Santos *et al.* (1994a) differed from those observed in this study regarding the number of grains per pod. They did not find significant differences in this trait for the treatments considered whereas results from this study indicate that soybean grown under NT produced lower average values of grains per pod compared to that grown under NT or RT conditions. As in the case of the number of pods per plant, number of grains per pod was affected by an interaction of the studied factors which may have caused the observed differences.

Crop yield showed no significant differences regarding the tillage systems and covers studied. These results are in accordance with those obtained by Derpsch *et al.* (1985) and Santos *et al.* (1994b) who studied soybean cultures under different tillage systems after black oat covers. In addition, Kluthcouski *et al.* (2000) observed the same between different tillage systems. However, Barrios *et al.* (2006) observed significantly higher yields in soybean crops under CT than in NT systems in a rotation maize/soybean. Lopes *et al.* (2007) found significantly higher yields in soybean crops under CT compared to NT depending on the previous cover used, which were different from the ones used in the current study. Other authors such as Di Ciocco *et al.* (2008) reported higher values for NT conditions.

In the current study, the highest value for crop yield was observed under CT conditions after a spontaneus vegetation cover, 1530 kg ha^{-1}. Although not significant, this value was 298 kg ha^{-1} higher than that observed under NT system after spontaneous vegetation cover, which presented the lowest yield value. CT promoted higher yields likely because of higher incorporation of vegetal residues into the soil, mineralization, and nutrient availability for plants. Lower yield values under NT conditions occurred because of the lower numbers of grains per pod, and pods per plant associated with a higher soil compaction along the four years during which this NT was established, a similar explanation was suggested by Ferreras *et al.* (2001). Yield values were lesser than those find by Lopes *et al.* (2007) who studied the effect of various covers on soybean crops, furthermore, they identified significant differences in the yields from NT and CT conditions, being higher those under CT, probably due to the effect of fertilizers. In our case, equivalent results among treatments are in accordance with the results obtained by Kluthcouski *et al.* (2000).

Since plant height, plant density, and height of the first-pod insertion did not show significant differences among treatments, these variables can be considered more dependent on other factors, i.e. crop rotation or mycorrhiza nodulation, than those considered in this study. Thus, further research accounting for these factors are recommended.

In summary, the three cover crops analysed, i.e. black oat, sorghum, and spontaneous vegetation, can be considered as excelent coverages for preceding soybean in a crop rotation system.

As conclusions, under the conditions of this research, some soybean traits did not present significant differences among treatments. Hence, these characteristics are more dependent on other variables than those considered in this study. In addition, other traits, such as number of pods per plant and number of grains per pod, can be considered as good indicators of the soil management. The fact that no significant differences were found in the soybean yields under the different soil tillage systems makes difficult to conclude what practice is the best for achieving greater yields.

Extrapolation of these results is difficult; however, they can be regarded as an useful basis for selecting plant traits on similar researches. In summary, the covers studied might be regarded as appropriate for preceding soybean in a crop rotation system.

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