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Agronomic performance of soybean in crop rotation systems

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Abstract

Crop rotation consists of alternating plant species cultivation in the same agricultural land, aiming to provide nutrient replenishment in the soil through organic matter deposition, as well as mitigating the soil degradation caused by agricultural practices. However, due to the short list of known crops suitable for such application, a selection of species to be inserted to the system is of critical importance. The objective of this research was to study the agronomic performance of soybean in crop rotation systems. The experiment was conducted at the Experimental Farm of the Faculty of Agricultural Sciences of UFGD, Dourados-MS, in two cropping seasons: 2013/2014 and 2014/2015; using a randomized block design with thirteen treatments and four replications. Treatments consisted of crop rotation systems in two soybeans cropping seasons. Corn, brachiaria, canola, wheat, forage turnip, safflower, crotalaria, niger, crambe, white oat, vetch and sunflower were the selected species to be inserted in the rotation systems. Six variables were analyzed: plant height, height of first pod insertion, number of branches per plant, number of pods per plant, mass of 1000 grains and grain yield. All collected data was submitted to analysis of variance and the means comparisons were analyzed by the Scott-Knott test (5%). This study revealed that crop rotation is an agricultural technique that favors the grain yield of soybean. Furthermore, during autumn and winter, fallowing is not recommended for soybean cultivation.

Keywords: *Glycine max*; Crop rotation; Yield; Fallow.
Abbreviation: m_meter; cm_centimeter; ha_acre; C_carbon; N_nitrogen; S_south; W_west; mm_millimeter; °C_degrees Celsius; B_boron; Zn_zinc; mL_millimeter; g_gram.

Introduction

The USA is the world's largest soybean producer, followed by Brazil. In the 2017/2018 cropping season, the world leader had a production of 131.5 Million metric tons, an area of 42.8 Million hectares, yielding 3.07 Metric tons per hectare. In the same cropping season, the Brazilian production reached 124.1 Million metric tons, in approximately 36.6 Million hectares of planted area, yielding an average productivity superior to the USA one - 3.39 Metric tons per hectare (Usda, 2018).
Adoption of non-conservative agricultural practices and the succession of soybean/corn have contributed to an increase in the incidence of plant diseases, pests and weeds, resulting in enlarged expenditures on labor, equipment and pesticides, since there are no plants in the system that contribute to inhibit the development of such harmful agents (Nunes et al., 2006).
In this way, the growing interest in the sustainability of agricultural systems has led to significant developments in farming practices, with emphasis on the prevention of erosion and soil degradation, through the direct planting system and minimum tillage. There is also growing interest in alternative forms of nutrient management, particularly the role of leguminous plants in N supply to non-leguminous species through intercropping and crop rotation (Martens et al., 2001). These practices have been increasingly adopted, given the greater attention to factors such as erosion, degradation, water storage capacity and thermal variability in the soil.
The lack or low amount of vegetation cover can increase the risk of water erosion, which, in turn, leads to a decrease in productivity and degradation of agricultural soils (Carvalho et al., 2007). As an alternative to mitigate such problems, the adoption of direct planting system has been suggested. By including systems of crop rotation, this alternative can be a viable form of management by accumulation of organic matter in the soil, which can alleviate problems, such as erosion, water storage, infestation by harmful agents, etc. Moveover, it enables incremental and sustainable increases in productivity with the improvement of the environmental quality (Heckler and Salton, 2002).
Crop rotation consists of alternating, in the same place, different cultures in a regular and logical sequence. Crop rotation with the use of plants of different species and with a root system that exploits the soil in a diversified manner contributes to the organic matter content of the soil. Thus, it is necessary to make use of species with vigorous root system and expressive contributions of dry matter inside the

system, which can alter the chemical and physical properties of the soil (Stone and Silveira, 2001).

The use of tropical forage plants has been applied as strategy to increase the contribution of straw to the soil and to guarantee physical, chemical and biological improvements, consequently increasing the productivity of the main crop and of the production system as a whole (Ceccon et al., 2013). According to Machado and Assis (2010), the use of pasture in crop areas, for periods of two years or longer, can improve the physical quality of the soils due to the increase in size and stability of the aggregates favored by the vegetal residues. Besides, it favors erosion control and soil resistance to compaction.

Ceccon et al. (2013) observed a lower level of weed infestation in intercropped crops or with single fodder, in the soybean crop, contributing to increased yields. Alves et al. (2013) when evaluating the cultivation of saffinha corn intercropped with *Urochloa ruziziensis* obtained an increase in corn production and better performance of soybean in succession; as well as Correia et al. (2013), who observed increased soybean yield grown after corn and brachiaria consortium.

The small number of known crops of agricultural interest that can be included in the crop rotation system has led to researchers to find some viable options of species to be included in the process. Freitas et al. (2016) showed that plants such as canola, crambe, niger and wheat can be grown in rotation systems with soybean. Souza et al. (2015) found that the crops of canola, crambe, safflower and forage turnip can also be inserted into crop rotation systems with soybean. Studies have shown improved agronomic performance of soybean when grown in crop rotation with different species (Ceccon et al., 2013; Krutzmann et al., 2013; Ferreira et al., 2015).

Considering the short known list of species described as viable options to be inserted in crop rotation systems with soybean, the present research aimed to study the agronomic performance of soybean [*Glycine max* (L.) Merrill] in crop rotation systems, using thirteen species: corn, brachiaria, canola, wheat, forage turnip, safflower, crotalaria, niger, crambe, white oat, vetch and sunflower.

Results and discussion

In the 2013/2014 cropping season, there was statistical difference ($p<0.05$) only for the grain yield variable of soybean. When soybean was grown after fallow, grain yield was lower than soybean followed by any crop evaluated in the present experiment (Table 1).

However, in the 2014/2015 cropping season a significant difference was observed in plant height and grain yield (Table 2). In the 2014/2015 cropping season the soybean plants submitted to treatments T1, T2, T3, T4, and T8 showed the lowest height. However, in none of the evaluated crop rotation systems the plant height obtained was comparable to the ones shown by the company holding the cultivar (BMX Potência RR), which is ± 1.12 m for the region in which the experiment was conducted (Mato Grosso do Sul-Brazil).

Plant height is an important characteristic within the evaluation of the agronomic performance of soybean, given that it can be one of the factors that favors lodging and is intrinsically linked to the genetic conditions of the plant, to the growing environment and to the plant population (Souza et al., 2013).

In both cropping seasons, the height of insertion of the first pod was higher than 10 cm for all evaluated treatments, contributing to the mechanized harvesting to avoid losses (Sediyama et al., 1985). It was also close to the value reported by the company holding the cultivar, which states around 16 cm.

It is known that plant height, pod insertion height and number of branches per plant are genetic characteristics of the cultivar, which can be influenced by the environment, mainly by soil fertility and climatice conditions (Mancin et al., 2009).

In both 2013/2014 and 2014/2015 cropping seasons (Tables 1 and 2, respectively), the mass of 1000 grains did not statistically differ. However, the yield of soybean grains was influenced by crop rotation systems. In both cropping seasons, the grain yield was lower under T1 (Fallow/Soybean/Fallow/Soybean), as productivity below 2,000 kg.ha^{-1}. According to Conab (2016), in the state of Mato Grosso do Sul-Brazil, where the experiment was conducted, the average soybean yield in the 2013/2014 cropping season was 2,900 kg.ha^{-1}. In the present study, the grain yields obtained in the other treatments (except T1), in the 2013/2014 cropping season, were close to this value, varying between 2,725 and 3,135 kg.ha^{-1}.

Thus, it is observed that fallowing, during Autumn and Winter, is not a recommended practice for the cultivation of soybean, in view of the low grain yield. The present study provides to the producer some feasible crop options of agricultural and environmental interest to be inserted in crop rotation systems in order to increase grain yield of soybean, besides all the already known advantages offered by the crop rotation systems.

Table 3 shows the mean values of dry biomass and the C/N ratio of the crops grown during Autumn and Winter, which are the predecessors of the soybean crop. According to Costa et al. (2010), the corn consortium with forages provides higher dry biomass production when compared to single corn cultivation, thus justifying the increase of grain yield of soybean when in series. For Machado and Assis (2010), *U. ruziziensis* species is a forage alternative when targeting the production of dry biomass for the cultivation system.

Previous researches reported increasing grain yields of soybean when in series with the corn consortium with forage, with emphasis to *U. ruziziensis* (Costa et al., 2010; Alves et al., 2013; Krutzmann et al., 2013). This fact may be due to the high input of dry biomass to the soil by this forage species (Table 3).

In the present study, it was verified that the crops of brachiaria, forage turnip, safflower, crotalaria and white oat presented values of dry biomass above 6,000 kg.ha^{-1}, which is, according to Alvarenga et al. (2001), the minimum ideal amount of straw for the soil cover when under direct planting system.

The lower grain yield observed when the soybean succeeded the fallow can be justified by the absence of plant residues left by the predecessor crops in the other crop rotation systems, given that dry biomass improves the physical, chemical and biological attributes of the soil. Andreola et al. (2000) emphasized that practices involving vegetation cover help controlling erosion and, in most cases, improve the availability of nutrients for the subsequent crop.

It is known that the production systems with greater diversity of plants increase the set of microorganisms, demonstrating the importance of the diversity of plants for

Table 1. Plant height, height of insertion of the first pod, number of branches per plant, number of pods per plant, mass of 1000 grains, and grain yield of soybean in crop rotation systems in the 2013/2014 cropping season.

Treatment	Plant height (cm)	Height of insertion of the first pod (cm)	Number of branches per plant	Number of pods per plant	Mass of 1000 grains (g)	Grain yield ($kg.ha^{-1}$)
2013/2014						
T1	55.3 ^{ns}	13.3 ^{ns}	2.5 ^{ns}	27.9 ^{ns}	170.80 ^{ns}	1.809 b
T2	53.7	13.2	2.9	41.7	170.30	2.790 a
T3	57.8	12.5	2.6	30.9	170.20	2.787 a
T4	65.3	13.9	3.5	41.7	177.40	3.135 a
T5	59.4	13.9	2.7	42.8	178.60	2.955 a
T6	61.6	13.1	2.9	40.0	176.90	2.825 a
T7	56.7	13.3	2.3	32.5	173.40	2.846 a
T8	60.7	13.0	2.4	37.7	185.10	2.846 a
T9	59.3	13.0	2.5	35.7	178.00	2.894 a
T10	59.5	13.8	2.9	33.3	179.80	2.725 a
T11	59.1	13.3	2.8	42.6	173.10	2.753 a
T12	57.6	12.2	2.9	42.4	180.60	2.892 a
T13	59.4	11.9	3.0	37.9	169.60	2.748 a
CV (%)	9.0	12.0	26.0	21.0	6.0	15.2

^{ns} Do not differ from each other by the F test ($p<0.05$).[1] Averages followed by the same letter do not differ significantly by the Scott-Knott test (5%).

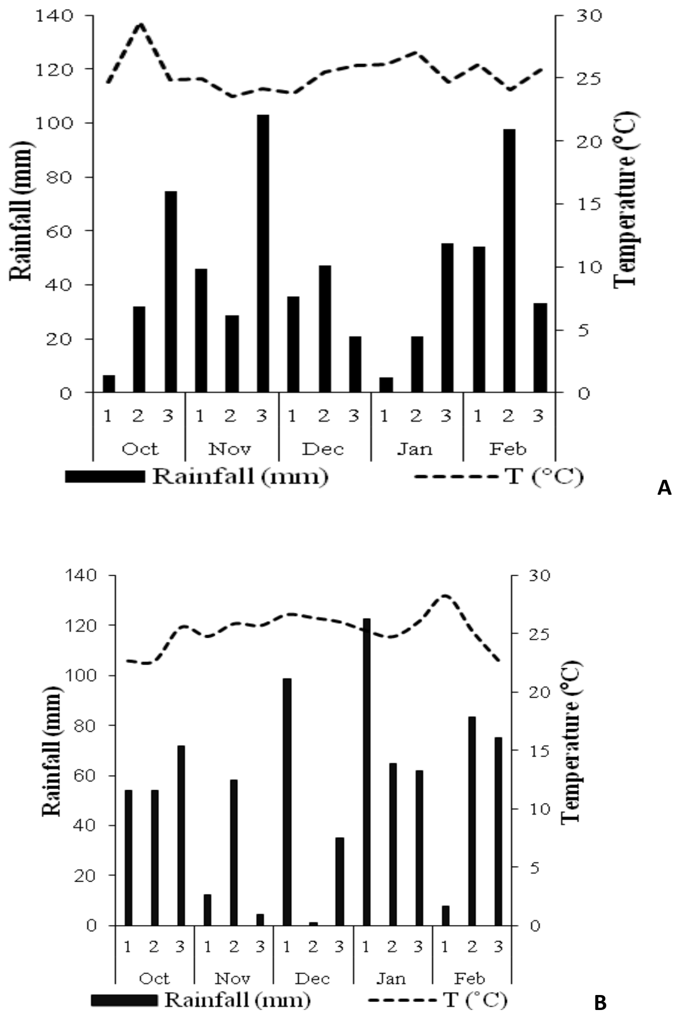

Figure 1. (A) Rainfall and average temperature per ten-day period of each month, from October/2013 to February/2014. (B) Rainfall and average temperature per ten-day period of each month, from October/2014 to February/2015. Source: Estação Meteorológica da Embrapa.

Table 2. Plant height, height of insertion of the first pod, number of branches per plant, number of pods per plant, mass of 1000 grains, and grain yield of soybean in crop rotation systems in the 2014/2015 cropping season.

Treatment	Plant height (cm)	Height of insertion of the first pod (cm)	Number of branches per plant	Number of pods per plant	Mass of 1000 grains (g)	Grain yield ($kg.ha^{-1}$)
2014/2015						
T1	89.1 b	15.7 [ns]	5.0 [ns]	53.0 [ns]	162.82 [ns]	1.988 b
T2	89.8 b	14.9	3.1	50.6	149.82	2.862 a
T3	93.0 b	16.6	5.0	58.0	164.23	2.814 a
T4	90.7 b	19.3	5.9	53.0	159.57	2.912 a
T5	97.8 a	16.2	4.9	62.4	151.78	2.635 a
T6	95.6 a	14.1	3.4	55.8	161.61	2.666 a
T7	94.7 a	16.4	3.6	57.0	148.44	2.489 a
T8	88.2 b	17.5	3.7	45.7	136.30	2.575 a
T9	95.5 a	13.8	3.0	51.6	143.41	2.424 a
T10	97.4 a	17.2	2.8	48.0	149.65	2.416 a
T11	94.8 a	14.9	2.9	52.4	153.47	2.451 a
T12	101.1 a	19.2	3.1	39.4	150.10	2.897 a
T13	101.3 a	16.3	3.7	47.2	168.68	2.866 a
CV (%)	4.2	11.0	34.0	23.9	11.0	19.6

[ns] Do not differ from each other by the F test ($p<0.05$).[1] Averages followed by the same letter do not differ significantly by the Scott-Knott test (5%).

Table 3. Average dry biomass yield after harvest of soybean (Autumn and Wnter crops) and C/N ratio.

Culture predecessor to soybean	Dry biomass ($mg.ha^{-1}$)	C/N ratio
Corn	5.17	53.0
Corn + Brachiaria	5.61	48.0
Brachiaria	7.50	35.0
Canola	3.70	20.0
Wheat	5.08	29.0
Forage turnip	6.10	22.0
Safflower	6.20	30.0
Crotalaria	6.10	13.0
Niger	4.20	20.0
Crambe	4.80	14.0
White oat	6.00	32.0
Vetch	5.15	13.5

Table 4. Chemical analysis of soil sampled at depth 0-10 cm.

Treatment	pH $CaCl_2$	Al	Ca	Mg	H+Al	K	P	SB	T	V	Organic Matter
				$(mmol.dm^{-3})$			$(mg.dm^{-3})$	$(mmol.dm^{-3})$		(%)	$(g.kg^{-1})$
T1	5.42	1.58	55.69	18.54	19.11	4.28	14.76	78.51	97.63	78.95	25.4
T2	5.54	1.58	49.24	15.79	19.25	4.33	12.56	69.36	88.61	76.43	26.9
T3	5.23	1.88	45.46	15.42	19.53	4.27	14.35	65.15	84.68	74.40	27.5
T4	5.51	1.20	45.27	18.13	18.34	4.96	3.63	68.37	86.71	74.72	28.3
T5	5.03	0.75	57.53	21.01	24.69	5.51	14.58	84.05	108.74	75.83	29.5
T6	4.85	0.98	49.45	17.29	26.26	6.01	14.98	72.75	99.01	71.78	31.8
T7	5.34	0.53	58.12	23.86	23.94	5.56	11.81	87.53	111.48	76.41	29.7
T8	5.49	0.45	54.32	21.54	28.37	5.35	15.59	81.21	109.59	71.80	30.7
T9	5.04	0.68	49.92	18.78	32.75	5.09	14.10	73.79	106.55	68.28	29.9
T10	5.06	0.83	41.38	15.17	26.56	4.07	14.95	60.61	87.17	65.87	29.7
T11	5.59	1.88	57.66	19.26	24.14	3.88	9.38	80.79	97.54	71.45	27.8
T12	5.55	0.90	56.25	24.69	33.40	4.78	6.60	85.71	119.12	70.14	27.4
T13	5.50	0.90	53.91	25.20	18.63	6.70	9.07	85.82	104.45	81.21	30.4

Table 5. Treatments consisting of different crop rotation systems in the 2013/2014 cropping season.

Treatment	Winter 2013	Summer 2013/2014
T1	Fallow/Soybean/Fallow	Soybean
T2	Corn/Soybean/Corn	Soybean
T3	Corn and Brachiaria consortium (C+B)/Soybean/C+B	Soybean
T4	Canola/Corn/Brachiaria	Soybean
T5	Sunflower/Corn/Canola	Soybean
T6	Safflower/Corn/Wheat	Soybean
T7	Wheat/Corn/Forage turnip	Soybean
T8	Forage turnip/Corn/Safflower	Soybean
T9	Niger/Corn/Crotalaria	Soybean
T10	Crambe/Corn/Niger	Soybean
T11	Wheat/Corn/Crambe	Soybean
T12	Safflower/Corn/White oat	Soybean
T13	Sunflower/Corn/Vetch	Soybean

Table 6. Treatments consisting of different crop rotation systems in the 2014/2015 cropping season.

Treatment	Winter 2014	Summer 2014/2015
T1	Fallow/Soybean/Fallow	Soybean
T2	Corn/Soybean/Corn	Soybean
T3	Corn and Brachiaria consortium (C+B)/Soybean/C+B	Soybean
T4	Canola/Corn/Brachiaria	Soybean
T5	Sunflower/Corn/Canola	Soybean
T6	Safflower/Corn/Wheat	Soybean
T7	Wheat/Corn/Forage turnip	Soybean
T8	Forage turnip/Corn/Safflower	Soybean
T9	Niger/Corn/Crotalaria	Soybean
T10	Crambe/Corn/Niger	Soybean
T11	Crotalaria/Corn/Crambe	Soybean
T12	Vetch/Corn/White oat	Soybean
T13	White oat/Corn/Vetch	Soybean

the increase of the microbial community of the soil (Vieira et al., 2016); which benefits the production system in medium and long term.

Thus, it was found that, in comparison to fallowing, crop rotation provides higher yield of soybean grains. Thus, the producer has a greater number of options to work, given the fact that in the present study several crops of agricultural and environmental interest have been studied and revealed as viable options to integrate crop rotation systems.

Materials and methods

Study area characterization

The experiment was conducted at the Experimental Farm of the Faculty of Agricultural Sciences of the Universidade Federal da Grande Dourados (UFGD), located in the municipality of Dourados-MS, with geographical coordinates 22º 14'S, 54º 49'W and elevation of 458 m. The predominant soil in the experimental area is the Distroferric Red Latosol (Embrapa, 2006) with a clayey texture. The chemical analysis of soil from the sampling performed in September of 2012 is shown in Table 4.

The experiment was carried out in an area under direct planting system since 2009, when limestone and gypsum were applied, according to needs indicated by soil analysis. The climate, according to the classification of Koppen is Am (tropical monsoon climate). The total annual rainfall of the region is 1,400 to 1,500 mm and the average annual temperature is 22ºC.

Plant material and treatments

The experiment was conducted in two cropping seasons: 2013/2014 and 2014/2015. The experimental design was a randomized block with thirteen treatments and four replicates. Each experimental unit consisted of 35 m long by 15 m wide, totaling an area of 525 m^2.

Rainfall (mm) and mean temperature (ºC) were measured during the 2013/2014 and 2014/2015 cropping seasons (Figure 1), along the field experiment duration.

The species used in the crop rotation systems were: corn (*Zea mays* L.), brachiaria [*Urochloa ruziziensis* (R. *Germ* & *Evrard*)], canola (*Brassica napus* L.), wheat (*Triticum aestivum* L.), forage turnip (*Raphanus sativus* L. var. *oleiferus* Metzg.), safflower (*Carthamus tinctorius* L.), crotalaria (*Crotalaria spectabilis* Roth), niger (*Guizotia abyssinica* Cass.), crambe (*Crambe abyssinica* Hoechst), white oat (*Avena sativa* L.), vetch (*Vicia villosa* Roth) and sunflower (*Heliantus annuus* L.), which were grown during Autumn and Winter of each cropping seasons and implanted according to the recommendation for each species. In both cropping seasons, an experimental unit was evaluated with fallowing in Autumn and Winter, followed by soybean.

All treatments are detailed in tables 5 and 6, which consisted of crop rotation systems until the soybean crop (in Summer). Treatments had its agronomic performance evaluated in the 2013/2014 and 2014/2015 cropping seasons.

Soybean seeds of the cultivar BMX Potência RR® were used. Sowing occurred on 06th of October of 2013 (2013/2014 cropping season) and 22nd of October of 2014 (2014/2015 cropping season), using pneumatic seed drill Jumil® with seven rows of 45 cm spacing and seeding density of 16 plants.m^{-1}. Seed fertilization was 300 kg.ha-1 of the formulation 07-20-20 + 0.3% B + 0.3% Zn, seeds were inoculated with the commercial product Masterfix®. Weed control was carried out with the glyphosate herbicide at the dosage of 3 L.ha^{-1}. The control of bedbugs was done with the insecticide Tiametoxam + Lambda-Cialotrina, at dose 200 mL.ha^{-1}.

Experimental design and traits measured

The straw was collected after harvesting each of the Autumn and Winter crops, in an area of 0.25 m^2, which was placed for drying in a forced circulation oven at 60ºC. Finally, the weighing was carried out and the value was extrapolated to 1 hectare. Then, the dry straw was ground and subjected to chemical analysis to determine Nitrogen (N) content, following the procedures described by Bataglia et al. (1983) and Carbon (C) content by the method described by Tedesco et al. (1985). In turn, the C/N ratio of the materials deposited on the soil was calculated.

Soybean was manually harvested in February/2013 and February/2014, in two rows of 5 m, sampled at random within each plot. The variables analyzed in the evaluation of the agronomic performance of the soybean crop were: plant height (cm), height of insertion of the first pod (cm), number

of branches per plant, number of pods per plant, mass of 1000 grains (g), and grain yield (kg.ha^{-1}).
Data were submitted to analysis of variance and means were compared using the Scott-Knott test (5%).

Conclusions

This study revealed that crop rotation is an agricultural technique that favors the grain yield of soybean. Furthermore, during Autumn and Winter, fallowing is not recommended for soybean cultivation.

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