Journal of the Brazilian Association of Agricultural Engineering
ISSN: 1809-4430 (on-line)

DESICCATION TIME OF THE SPRING SORGHUM AS A PREDECESSOR CROP FOR SUMMER SOYBEAN AND AUTUMN BEAN IN A NO-TILLAGE SYSTEM

Doi:http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v36n1p94-101/2016

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ABSTRACT: Several authors have been questioned the desiccation interval between the coverage plants and sowing plants for the soybean crop. Therefore, this study aimed to evaluate the desiccation time of the spring sorghum as a predecessor crop for summer soybean and then for autumn bean, focusing on the straw formation for maintenance of the no-tillage system and to evaluate the yield of soybeans and beans grain, as well as analyzing the interference of sorghum straw in these cultures. The experiment was developed in the Teaching and Research Farm of FE/UNESP located in Ilha Solteira/SP where it was used an experimental design of randomized blocks with five treatments and six repetitions. The treatments consisted of five different intervals between sorghum desiccation and soybean sowing (being with D7 - Drying sorghum seven days before the soybean sowing; and successively for D14, D21, D28 and D35). In order to analyze the results, it was used the Tukey test for a 10% level of significance and the statistical program called Sisvar. The "Cober Crop" sorghum exerted influence on soybean yield but this effect was not lasting for the bean crop in succession to the soybeans.

KEYWORDS: exudates allelochemicals, soil cover, desiccation interval for sowing, crop rotation, straw production.

ÉPOCAS DE DESSECAÇÃO DO SORGO PRIMAVERIL COMO CULTURA ANTECESSORA DA SOJA DE VERÃO E DO FEIJÃO DE OUTONO EM PLANTIO DIRETO

RESUMO: O intervalo de dessecação entre plantas de cobertura e semeadura da soja vem sendo questionado por diversos autores. O trabalho teve como objetivo avaliar intervalos de dessecação do sorgo de primavera como cultura antecessora da soja de verão e, posteriormente, a cultura do feijão no outono, com ênfase para a formação de palhada para a manutenção do Sistema Plantio Direto e para melhorar a produtividade de grãos da soja e feijão, bem como analisar a interferência da palhada de sorgo nessas culturas. O ensaio foi desenvolvido na Fazenda de Ensino e Pesquisa da FE/UNESP – Ilha Solteira, sendo o delineamento experimental o de blocos casualizados, com 5 tratamentos e 6 repetições. Os tratamentos foram constituídos por 5 intervalos distintos entre dessecação do sorgo e semeadura da soja (sendo D7- Dessecação do sorgo 7 dias antes da semeadura da soja; e assim, sucessivamente, para D14, D21, D28 e D35). Para a análise dos resultados, foi utilizado o teste de Tukey para um nível de significância de 10% e o programa estatístico Sisvar. O sorgo "Cober Crop" exerceu influência sobre a produtividade da soja, e seu efeito não foi duradouro para o cultivo do feijão em sucessão à soja.

PALAVRAS-CHAVE: exsudados aleloquímicos, cobertura de solo, intervalo de dessecação para semeadura, sucessão de culturas, produção de palha.

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Recebido pelo Conselho Editorial em: 22-11-2013
Aprovado pelo Conselho Editorial em: 27-11-2015

INTRODUCTION

Sorghum, *Sorghum spp*. (Poaceae), as it stands today, it is a man's intervention product, that has been transformed according to human needs. This plant is a C4 plant that has short days with high photosynthetic rate and high ability to tolerate drought, which make this plant an important alternative for planting in hot and dry regions (MAGALHÃES et al., 2009).

In Brazil, sorghum cultivation made a significant progress in recent years. According to RODRIGUES (2009), this growth is explained by the high grain production potential and high production of dry matter, as well as its extraordinary ability to withstand environmental stresses.

The culture adaptation zones are concentrated in South of Brazil especially in summer crops. In the Central Brazil, they are concentrated in succession to summer crops and in the Northeast of Brazil in plantations in the semiarid region. Currently, sorghum cultivation occurs mainly in succession plantings, especially in the states of São Paulo, Goiás, Mato Grosso, Mato Grosso do Sul and in the Mineiro Triangle region, where concentrates approximately 90% of sorghum grain planted in Brazil (TARDIN et al., 2009).

Despite the high productive potential of sorghum and the wide availability of cultivars with characteristics that allow good adaptations of these materials to different regions, it is common to find low production (MACEDO et al., 2012). MAGALHÃES et al. (2010) studying 25 sorghum hybrids showed that the VOLUMAX genotype had higher yield, producing 16.1 t ha^{-1} of dry matter.

Several plants can be used as cover crops, but sorghum stands out due to the ease of planting and management (BOTELHO et al., 2010). According to MELLO et al. (2004), sorghum is a viable alternative because of the ability to meet the annual intake of dry mass straw that is necessary for the no-tillage maintenance.

Sorghum residues left on the soil surface can have allelopathic effect on soybeans, depending on the cultivar and the local conditions (OLIBONE et al., 2006). Leaves, stems and sorghum roots are the plant parts that have greater allelopathic activity (BEN-HAMMOUDA et al., 1995). It was found that soybean seedlings treated with these extracts have lower radicle compared to the control plants (CORREIA et al., 2005).

This compound in an oxidized form and is known as sorgoleone, being currently one of the most studied allelochemical (UDDIN et al, 2010; DAYAN et al., 2010). Exclusively, sorghum root hair produces benzoquinone lipophilic sorgoleone (COOK et al, 2010). In addition, according to DAYAN et al. (2010), sorgoleone is a potent allelochemical, consisting of an oily exudate secreted from sorghum root.

Studies conducted by FRANCO et al. (2011) showed that this allelopathic potential of sorghum is so important that has being studied as a bio-herbicide, since it may affect in the development of other plants. DAYAN et al. (2009) also said that these allelochemicals are environment friendly options once they are kind of natural herbicides. In addition, according to DAYAN et al. (2012), these natural herbicides can act on different targets from those commonly found for synthetic herbicides.

Sorghum stands out as an alternative to crop rotation in the fall/winter period, because it is tolerant to unfavorable moisture conditions and produces great amount of dry matter with high C/N ratio. Therefore, it constitutes an excellent cover for establishing and/or maintaining of the no-tillage system (CORREIA et al., 2005). In addition, according to ANDRADE NETO et al. (2010), sorghum has significant increase of dry matter starting at 80 days after sowing.

Soybeans [*Glycine max* (L.) Merril] is an herbaceous annual legume with high protein content in grains (average of 38%) and easy adaptation into different climate and photoperiod conditions, which make this plant one of the most important oilseed plant in the world (BERTRAND et al., 1987). The national production of soybean, crop 2014/15, was estimated at 96.04 million tons (CONAB, 2015). According to SILVA & ROSOLEM (2001), soybean nutrition shows better performance when grown in succession cover crops in an originally compacted soil.

On the other hand, RICCE et al. (2011) showed that large amounts of straw during sowing day could reduce plant plots; however, this reduction is offset by increasing number of pods per plant and thus not affecting soybean average yield.

Sorghum desiccation time as predecessor crop of soybeans is an issue that has been questioned by several researchers as a quite important factor in soybean production. Since there are different management intervals of straw, desiccation concurrently with sowing or in the next day may be harmful to commercial crop yields (CONSTANTIN et al., 2005).

In this way, the purpose of this study was to evaluate different sorghum desiccation intervals, prior to soybean sowing, with subsequent bean sowing to evaluate the residual effect of desiccation intervals.

MATERIAL AND METHODS

The study was conducted at an Experimental Farm located in the city of Selvíria/ MS belonging to UNESP of Ilha Solteira (51º24'07" W, 20º20'52" S and 335 meter altitude). The area has been under no-tillage system (NTS) for 17 years and has received supplementary irrigation by self-propelled cannon. Before the first sowing of the experiment, weed control was performed by desiccation with glyphosate at 1.44 kg a.i ha^{-1}.

The experiment was divided into two parts. The first consisted of sowing sorghum "Cober Crop" cultivar over the entire area for using a non-tillage system. The second started after desiccation up to sowing of soybean MG/ BR 46 (Conquista). The treatments were five intervals between sorghum desiccation and soybean sowing; which were 7, 14, 21, 28 and 35 days. After soybean harvest, we sown beans of Rubi cultivar, also under non-tillage system, to assess possible residual effects of the sorghum desiccation intervals. The experimental design was randomized blocks with five treatments and six replications.

Sorghum, soybeans and beans were sown at a 0.45 m spacing wherein each plot occupied an area of 120 m^2. Agronomic evaluations were held by the end of crop cycle assessing plants from the four central rows of each plot, excluding one meter from both ends as border. Weed was controlled in accordance with local and crop infestations, using a sprayer mounted on a three-point system tractor. Results were analyzed by the Tukey's test at 10% significance level using Sisvar statistical software.

Sorghum

Before sowing, sorghum seeds were treated with fungicide and insecticide. Sowing was carried with 22 sorghum seeds per meter for all plots, as well as 200 kg ha^{-1} of a sowing fertilization with the following commercial formula 08-28-16. Top-dressing was not performed in this treatment. We evaluated the following parameters fresh mass, dry mass, plant height and final plant plot. The fresh mass was obtained by cutting sorghum plants in composite sample. The dry mass was get by drying the fresh mass samples in an oven at 65ºC until to reach constant weight. The plant height was obtained using a graduated ruler and measuring the height average of 10 random plants in each plot. Finally, in order to estimate the final plant plot was counted the number of plants present in two rows of three meters at each plot.

With the purpose to standardize soybean sowing and thus minimize environmental effects, the first desiccation was held at 47 days after sowing (DDS47-D35); and thus, every seven days, the following treatment was desiccated, until it reaches 7-day treatment interval to 75 days of sorghum crop implantation (DDS75-D7).

Soybean

Soybean, *Glicine max* L. Merrill, was sown in all plots seven days after the last sorghum desiccation treatment on the five treatments, using 16 seeds per meter and adding 250 kg ha^{-1} of a sowing fertilization that has the following commercial formula 02-30-20. In the top-dressing, was applied 100 kg ha^{-1} of the potassium chloride in all plots. We evaluated the following parameters plant height and height insertion of the first pod, obtained by measuring 10 random plants in each plot and using a graduated ruler. It was also evaluated the number of pods per plant, measuring then at the maturity time, at the R8 stage and counting the number of pods in the 10 assessed plants. It was also studied the dry mass of plants and the grain production by collecting plants in the useful area of each plot, with subsequent track. The values was extrapolated for kg ha^{-1} and the moisture was corrected to 13%.

Bean

Bean crop, *Phaseolus vulgaris* L., was also seeded in the same period for all treatments in the NTS area, in succession to soybean. In addition, 11 seeds per meter of the Rubi cultivar was planted together with 250 kg ha^{-1} of the sowing fertilization that has the following commercial formula 02-30-20. In top-dressing, was applied 100 kg ha^{-1} of urea in all plots. We evaluated the parameters plant height, height insertion of the first pod, number of pods per plant, dry mass, grain production and 100-grain weight. In this way, it was weighed 100 grain of 10 plants collected at random in each plot using an analytical balance and finally, the weight was converted to a moisture of 13%.

RESULTS AND DISCUSSION

The average values of fresh mass production, dry mass production, dry matter percentage, plant height and number of plants per meter of sorghum are shown in the Table 1. It was observed that the fresh mass production (GM) had a parabolic result ($GM = -1.1514\ (DDS)^2 + 13.387\ (DDS) + 6.54$) decreasing the average increment more sharply in the plots with sorghum in the DDS68 and 75. This indicates that there is a period and/or a desiccation and harvesting interval more appropriate for the crop, facilitating the soil management for the subsequent crops. The results showed significant differences by Tukey test at 10% probability, with the highest values obtained in DDS61, DDS68 and DDS75 treatments.

TABLE 1. Fresh mass production- GM (kg ha^{-1}), dry mass – DM (kg ha^{-1}), dry matter percentage – %DM, plant height PH (m), final plant plot (plants m.$linear^{-1}$) of sorghum Cober Crop (FPP).

Treatments *	Evaluated parameters				
	GM	DM	%DM	PH	FPP
DDS75-D7	44,416 a	14,406 a	32.39 a	2.14 a	17.48 a
DDS68-D14	42,046 a	9,086 b	21.60 bc	2.04 a	16.93 a
DDS61-D21	36,777 a	7,575 bc	20.36 b	1.62 b	17.43 a
DDS54-D28	27,731 b	6,145 c	21.76 b	1.25 c	18.05 a
DDS47-D35	19,185 c	3,441 d	18.01 c	0.99 d	17.10 a
F value	21.037	41.661	37.193	148.711	0.635
CV (%)	16.45	19.04	9.77	6.18	7.59
DMS	8,542.26	8,130.87	3.40	0.15	2.02

Average followed by the same letter do not differ by the Tukey's test at 10% probability. *"DDS" refers to sorghum age in days after sowing, and "D" the interval between desiccation and sowing of soybean, for example "DDS75-D7" means that sorghum was with 75 days after sowing and was dried out seven days before soybean sowing.

The results indicated that sorghum should be used as forage from 61 DDS until 75 DDS. The dry mass production and the dry mass percentage showed similar behavior to the fresh mass, showing increased production until 75 DDS. In addition, the fastest growing internal happened between DDS-68 and DDS-75, when the flowering period occurred. In conclusion, the best desiccation time, when the purpose is the formation of straw, was observed in the DDS-75 treatment with 14.4 t ha^{-1} of dry matter. MAGALHÃES et al. (2010) found in their experiment, maximum production of 16.1 t ha^{-1} of dry matter among the 25 evaluated sorghum hybrids, which is close to the results found in this experiment. In this way, the best time for the forage production and dry mass straw is very important because it provides enough subsidies in order to make the right decisions. The low dry mass production in the first ages can produce negative effect on the maintenance of the soil cover. Therefore, it was observed that the treatments studied have exponentially higher values, which means that they are more sustainable.

The plant height also had significant differences evidenced by the Tukey test for a level of 10% of probability, showing that there is a continued growth from DDS47 to DDS68. In the DDS75 treatment, the plant height was higher in absolute values due to flowering. As shown in the Table 1, the treatments did not differ among themselves especially when analyzing the plant plot, which means that there is a sowing uniformity. In addition, all the parameters studied obtained low coefficient of variation. These results indicated that there is high probability of repetition of this results when applied the knowledge acquired in this experiment.

Table 2 demonstrates the average values of soybean yield, total dry mass, number of pods per plant, plant height and height insertion of the first pod. It was observed that the yield had significant differences between treatments confirmed by the Tukey's test at 10% probability. This result confirms sorghum allelopathic effect on soybean production.

This allelopathic effect appears to be exacerbated beyond the interval of sorghum drying and soybean planting, as well as various amounts of dry mass available from dissections in different DDS sorghum. These differences in mass quantities are due to field reality. There are different and close periods of useful days to do agricultural operations within the time limits established as ideals.

TABLE 2. Yield – Y (kg ha^{-1}), total dry matter – TDM (kg ha^{-1}), final plant plot – FPP, number of pods per plant - NPP, plant height - PH (m) and height insertion of the first pod of the soybean (m) – H1P

Treatments	Evaluated parameters					
	Y	TDM	FPP	NPP	PH	H1P
DDS75-D7	3,467 b	5,067 a	10.58 a	66 a	0.98 a	0.24 a
DDS68-D14	3,760 ab	5,860 ab	10.93 a	60 a	1.04 ab	0.26 a
DDS61-D21	3,980 ab	5,915 ab	10.77 a	65 a	1.06 ab	0.25 a
DDS54-D28	4,155 a	6,670 b	11.06 a	60 a	1.10 b	0.25 a
DDS47-D35	3,909 ab	6,302 ab	11.25 a	64 a	1.12 b	0.26 a
F values	3.451	2.460	0.676	1.273	3.121	0.341
CV (%)	8.86	15.67	7.06	10.15	7.39	10.58
DMS	521	1,425	1.18	9.74	0.12	0.04

Averages followed by the same letter do not differ by the Tukey's test at 10% probability.

Tukey's test evidenced that dry mass production and grain production had the same behavior at 10% probability. The highest soybean grain and dry mass productions were observed for D28; however, not differing significantly from D14, D21 and D35. Therefore, aiming for higher productions, desiccation should be carried around 14 days before sowing, with the best results recorded at 28 days. In this way, intervals shorter than 14 days generates lower soybean yields, being less profitable to farmers.

According to SANTOS et al. (2007), soybean dissection and sowing carried within the same day may affect crop development and promote negative effects on the soil microorganism activity.

Moreover, the interval between dissection and sowing of glyphosate-resistant cultivars should be inferior to seven days.

SILVA et al. (2006), studying *B. brizantha*, observed that intervals above 14 days do not interfere with plant physical characteristics. Yet Nepomuceno et al. (2012), who studied *U. ruziziensis* desiccation preceding soybean sowing, concluded that periods of 10 to 20 days before sowing do not affect soybean yields. NUNES et al. (2009) also said that the most appropriate time for chemical management of *B. decumbens* is between 7 and 14 days before soybean sowing. In other words, as shown by the above-mentioned authors, forage species affect soybean growth and production, and ideal desiccation is within 14 days before soybean sowing, as found in this study.

Plant plot analysis showed that the number of plants per meter did not differ statistically among all treatments. This result indicates sowing uniformity and lack of interference by desiccation periods within the initial phase of soybeans. Studies conducted by MONQUERO et al. (2010) found similar results for the initial phase of soybeans. These authors ascertained that dissection time of *B. ruziziensis* had no influence on soybean leaf area in the early development; conversely, plant heights showed differences with desiccation time and coverage plant species.

Number of pods per plant and first pod height insertion did not differ significantly. Plant height results indicate statistical differences between D35 and D7. This result can be explained by sorghum allelopathic effect on soybean plants.

Table 3 shows the average yield, total dry mass, plant height, insertion of first pod, pod number and 100-grain weight, from which we observed no significant difference among treatments. This difference means that managing grain crops after sorghum has no interference regarding desiccation season. According to VALENTINI et al. (2001), different management time preceding direct sowing of beans (0, 15 and 30 day before sowing) evidenced no effect on plant population or even grain yield. This result may be related to the end of negative effects from desiccation interval.

TABLE 3. Yield – Y (kg ha^{-1}), total dry matter – TDM (kg ha^{-1}), plant height - PH (m), height insertion of the first pod – H1P (m), number of pods per plant – NPP, and 100-grain weight of bean – W100 (g).

Treatments	Evaluated parameters					
	Y	TDM	PH	H1P	NPP	W100
DDS75-D7	2,566	2,142	0.93	0.18	12.47	28.64
DDS68-D14	2,453	2,323	0.91	0.18	10.50	27.41
DDS61-D21	2,438	2,302	0.89	0.20	11.72	27.76
DDS54-D28	2,409	2,317	0.89	0.18	12.43	28.11
DDS47-D35	2,653	2,210	0.90	0.20	11.38	27.91
F value	0.513	0.465	0.192	1.42	0.898	1.011
CV(%)	14.01	12.69	9.73	10.03	18.04	3.99
DMS	595	486	0.149	0.008	3.58	1.895

Averages followed by the same letter do not differ by the Tukey's test at 10% probability.

Despite the different amounts of sorghum and soybean straw, Table 3 indicates soybean production uniformity. These results become an important tool since literature studies on this topic are deficient, mainly regarding the effects of sorghum straw "Cober Crop". Such lack of information may rely on the fact that this use of sorghum straw on crop succession is relatively new in the market.

CONCLUSIONS

Dry mass production and sorghum "Cober Crop" dry matter percentage increased until 75 days after sowing. Therefore, sorghum must be dried out 75 days after sowing to be used for straw formation in no-tillage systems.

The desiccation of "Cober Crop" sorghum, which is used as crop cover, near soybean sowing promoted negative effect on grain production, total dry mass and plant height.

The best interval from sorghum desiccation and soybean sowing is of at least 14 days to enhance soybean production.

The negative effects of different intervals between forage sorghum desiccation and further soybean sowing were not expressed in bean crop planted in succession in a no-tillage system.

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