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CROP PRODUCTION

Overseeding annual summer pastures on soybean crops to overcome the autumnal forage shortage

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ABSTRACT: In integrated crop-livestock systems, overseeding annual summer pastures over grain crops can reduce forage shortages in autumn without altering grain production. This study evaluated the influence of pearl millet (*Pennisetum glaucum* L.) and sudangrass (*Sorghum Sudanese*) overseeded on a soybean (*Glycine Max*) crop or no-tillage seeding after soybean harvest on productive aspects of pasture. The experimental design was a randomized block with treatments in a 2 × 2 factorial arrangement (pearl millet or sudangrass, overseeding in the full seed stage (R6) of soybean crops or seeding them in a no-tillage system after soybean harvest) in two agricultural years. Pasture height, plant stand, tiller density, and forage production were higher in the first crop year. The overseeding strategy resulted in higher pasture height and foraged production in the first crop year and higher pasture utilization for the next two crop years. Under the no-tillage strategy, the plants stand more elevated in the first crop year, resulting in a higher tiller density in the second crop year. Pasture height, utilization period, and forage production did not differ among the forage species. Pearl millet had a more elevated plant stand, while sudangrass had a higher tiller density. Annual summer pasture overseeding of soybean crops increases the pasture utilization period and forage production in autumn.
Key words: forage production, seeding methods, tiller density, pasture utilization period.

Sobressemeadura de pastos anuais de verão na cultura da soja para suprir a escassez de foragem outonal

RESUMO: Em sistemas integrados de produção agropecuária, a sobressemeadura de pastagens anuais de verão sobre as lavouras de grãos, pode reduzir a escassez de forragem no outono sem alterar a produção de grãos. Este trabalho avaliou a influência do milheto (*Pennisetum glaucum* L.) e do capim-sudão (*Sorghum Sudanese*) sobressemeados na lavoura de soja (*Glycine Max*) ou semeadura em plantio direto após a colheita da soja sobre os aspectos produtivos da pastagem. O delineamento experimental foi em blocos casualizados com tratamentos em arranjo fatorial 2 × 2 (milheto ou capim-sudão, semeadura no estádio (R6) da lavoura de soja ou semeadura em sistema de plantio direto após a colheita da soja) em dois anos. A altura do pasto, estande de plantas, densidade de perfilhos e produção de forragem foram maiores no primeiro ano agrícola. A estratégia de sobressemeadura resultou em maior altura de pastagem e produção de forragem na primeira safra e maior utilização da pastagem nas duas safras. Na estratégia de plantio direto, as plantas ficaram mais elevadas no primeiro ano e com maior densidade de perfilhos no segundo ano agrícola. A altura do pasto, o período de utilização e a produção de forragem não diferiram entre as espécies forrageiras. O milheto apresentou estande de plantas mais elevado, enquanto o capim-sudão apresentou maior densidade de perfilhos. A sobressemeadura anual das pastagens de verão na cultura da soja aumenta o período de utilização das pastagens e a produção de forragem no outono.
Palavras-chave: produção de forragem, métodos de semeadura, densidade de perfilhos, período de utilização do pasto.

INTRODUCTION

An increase in the global population challenges the sustainable growth of food (OLIVEIRA et al., 2017). This challenge is prominent in Brazil, where low productivity and environmentally degrading agricultural activities occupy vast areas (REIS et al., 2021). Integrated crop-livestock systems (ICLS) have emerged as an alternative to reconcile the increase in food production with environmental preservation (MOOJEN et al., 2022). However, according to these researchers, using ICLS modifies simple, pure agricultural systems into more complex, knowledge-demanding production systems.

Livestock production in ICLS highly depends on many factors, mainly the grazing period (CAMPBELL & KING, 2022). The grazing period can be increased by sowing early pastures over cereal crops (e.g., Urochloa sp. in soybean crops) without altering the production of grain crops (BAPTISTELLA et al., 2020). However, annual summer grasses, such as pearl millet, are widely used in Central-Western Brazil, mainly as a cover crop after the grain crop (DE ASSIS et al., 2018).

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These areas are rarely used for livestock production. In addition, the duration of pasture usage can be short because of subsequent dry periods. Early sowing of forage seeds over cash crops can increase pasture utilization time. Studies have shown that early sowing of pearl millet in soybean crops can improve soil conservation (PACHECO et al., 2008; DE ASSIS et al., 2018). However, the number of studies evaluating the planting of pearl millet and sudangrass on grain crops for grazing is limited.

The early sowing of winter pasture in grain crops has already been studied in subtropical and temperate regions (PILECCO et al., 2019; WILSON et al., 2019). Thus, showing several benefits (increase in grazing period, forage production, weed reduction, and lower N_2O emissions). However, when grain harvest occurs in mid-summer for various reasons (crop rotation, climatic factors, and ICLS objectives), the use of an annual summer pasture overseeding the grain crop can be an alternative to reduce the forage shortage until winter pastures are established.

Therefore, we hypothesized that: (1) the overseeding of pearl millet and sudangrass on soybean cash crop reduces the autumn forage shortage in subtropical regions and (2) the overseeding of pearl millet and sudangrass on soybean increases the period of use of pasture and forage production. This study evaluated the influence of overseeding pearl millet and sudangrass on soybean production aspects of pasture under a defoliation regime. Productive responses were assessed based on the forage accumulation rate, production, pasture utilization, tiller density, plant stand, and height.

MATERIALS AND METHODS

This study was carried out in Renascença (26° 17' 47.4" S, 52° 54' 21.3" W; altitude of 780 m), Paraná, Brazil. The soil in the area was classified as red latosol. The climate of the region is classified as Cfa type (humid subtropical) according to the Köppen classification system (ALVARES et al., 2013), characterized by relatively high temperatures and evenly distributed precipitation throughout the year. Meteorological data observed throughout the experimental period are discussed in table 1. The soil was collected at 0–0.2 m depth with the following chemical characteristics: pH ($CaCl_2$), 5.60; P, 23.86 $mg \cdot dm^{-3}$; K+, 0.58 $mg \cdot dm^{-3}$, H+Al, 4.21 $cmolc \cdot dm^{-3}$; the sum of bases, 11.03 $cmolc \cdot dm^{-3}$; cation-exchange capacity, 15.24 cmolc dm^{-3}; percent base saturation, 72.38; and organic matter, 56.29 $g \cdot dm^{-3}$.

Experimental protocol

The experimental design was a randomized block design with the treatments in a 2 × 2 factorial arrangement (pearl millet or sudangrass, overseeded on the previous soybean crop harvest or no-tillage sowing after soybean harvest) in two agricultural years, using eight area replications/treatment/year. At the full seed stage (R6), the soybean crop, cultivar NS5445, was overseeded manually on February 22, 2019, and February 27, 2020. Sowing after the soybean harvest was carried out with a continuous flow no-tillage seeder-tiller, with an inter-row spacing of 17 cm and a depth of 2.5 cm. This sowing was performed immediately after the soybean harvest without desiccation (March 26, 2019, and March 18, 2020).

In the no-tillage strategy, the seeding densities were 15 $kg \cdot ha^{-1}$ and 25 $kg \cdot ha^{-1}$ for pearl millet, cultivar ANm 38, and sudangrass, cultivar BRS estribo, respectively. In the overseeding strategy, the seeding density was 30 % higher (19.5 $kg \cdot ha^{-1}$ of pearl millet and 32.5 $kg \cdot ha^{-1}$ of sudangrass). The formulated NPK 8-20-15 (330 $kg \cdot ha^{-1}$) was used for base fertilization in both sowing methods. Covering fertilization was done manually with urea (45 % N) at the tillering of each forage, whereas in the no-tillage treatment at a dose of 100 kg N ha^{-1} (April 13, 2019, and March 20, 2020, first and second crop years, respectively), and the overseeding treatment at a dose of 200 kg N ha^{-1} (April 26, 2019, and March 25, 2020, first and second crop years, respectively).

Pasture height was determined based on the average point of leaf curvature (FRAME, 1981) with a graduated ruler at five random points per plot. Except for the pasture height measurement at the time of soybean harvest, the other measures were taken at the time of forage mass evaluation, which varied as a function of the time taken to reach the cutting height. After 10, 20, and 30 days of pasture establishment (no-tillage: March 03, 2019, March 13, 2019, and March 23, 2019; overseeding: March 08, 2020; March 18, 2020, and March 28, 2020, respectively), the plant stand and tiller density were measured by visual counting at two random points (0.0625 m^2) per plot.

Forage production (FP, $kg \cdot DM \cdot ha^{-1}$) was determined by the cumulated value of forage produced at each sampling date. Therefore, FP was obtained by adding the edible forage mass (EFM, $kg \cdot DM \cdot ha^{-1}$) and residual mass of the first cut. The EFM was determined by cutting 50 % of the forage canopy (defoliation intensity 50 %) at two random points (0.25 m^2) per plot when the height of the pasture reached 40–50 cm. Tropical grasses maintain greater levels of average forage accumulation rate when lowered by 40 or 50 % of their initial height in relation to greater defoliation intensities (MARTINS et al., 2021). Residual mass was determined in the first cut at two points (0.25 m^2) after removing material from the first defoliation by cutting the forage close to the ground. Defoliation was performed using a brush cutter (Matsuyama 2Hp 51.7 cc) equipped with nylon threads. The first measurement of forage production after the overseeding treatment was conducted after the soybean harvest. At the time of the grain crop harvest, the grasses in the overseeding treatment had a lower average height (8 cm) than the soybean harvest height (10 cm). The forage samples were dried at 55 °C for 72 h to determine the dry matter (DM). The pasture utilization period was determined by the number of days between the first and last defoliation.

The dynamics of forage production were determined from the monthly forage accumulation rate (FAR, kg·DM·ha^{-1}·$month^{-1}$), which was determined by the weighted average between the accumulation rates of each cut and the days of accumulation of each month using the equation proposed by each cut and the days of accumulation of each month proposed by FERRAZZA et al. (2013): $FAR_{mi} = [(FAR_{x,\ x-1} \times NDM_{x,\ x-1}) + (FAR_{x,\ x+1} \times NDM_{x,\ x+1})] / ND_{mi}$, in which FAR_{mi} refers to the forage accumulation rate of given month *i*, $FAR_{x,\ x1}$ refers to the forage accumulation rate between the current cut (x) and the previous cut (x-1), $NDM_{x,\ x-1}$ refers to the number of days of the month *i* between cuts x and x-1, $FAR_{x,\ x+1}$ refers to the forage accumulation rate between the current cut (x) and the next cut (x+1), $NDM_{x,\ x+1}$ refers to the number of days in a month *i* between cuts x and x+1, and ND_{mi} refers to the number of days of the month *i*.

Data analysis

The data were analyzed (F test; α = 0.05) using PROC MIXED of SAS (*Statistical Analysis System*, version 9.2), considering fixed (treatments, year, treatment × year) and random (block, block × treatments) effects. When necessary, Tukey's test was used to compare the means (α = 0.05).

RESULTS AND DISCUSSION

Regardless of forage species, the overseeding strategy showed higher (P = 0.004) forage production in February, March, and May than the no-tillage strategy (Figure 1). The overseeding strategy allowed forage production to be more balanced during defoliation than the no-tillage strategy, with an average of 26 days to forage for canopy mechanical defoliation. The greater and better distribution of forage production during overseeding is related to the favorable conditions of temperature, humidity, and photoperiod associated with early sowing (Table 1).

Pasture height, plant stand, tiller density, and forage production were higher (P < 0.05) in the first crop year (Table 2). The pasture components

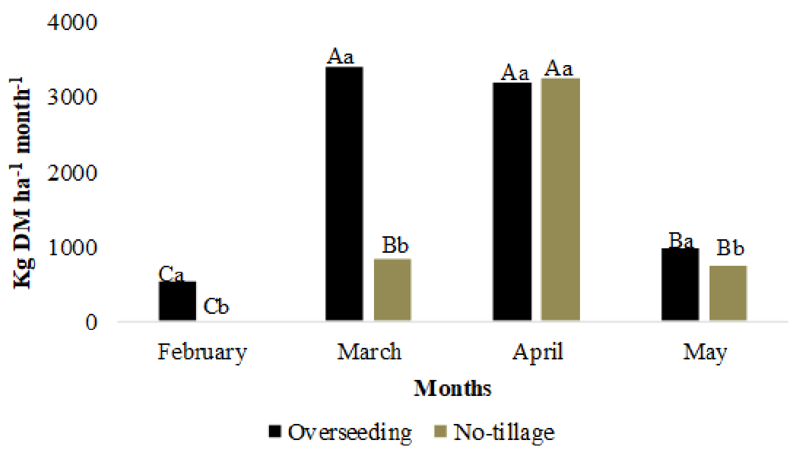

Figure 1 - Dynamics of the average forage production of the two agricultural years according to seeding strategy. Means followed by different capital letters indicate significant differences between months (P < 0.05). Means followed by different lowercase letters indicate differences between seeding strategies (P < 0.05).

Table 1 - Climatic characteristics during the experimental period.

Years	-------------Months-----------	-----Precipitation (mm)-----	----------Tmax (°C)----------	-----------Tmin (°C)---------
2019	February	166.6	27.7	17.7
	March	150.9	26.8	16.3
	April	150.8	25.4	15.4
	May	284.9	22.1	14.2
	June	38.3	21.8	11.5
	July	79.1	19	7.9
	August	33.4	21.8	8.2
	September	54.6	25.1	12.6
	October	136.9	28.8	16.1
	November	147.4	28.9	17.2
	December	109.3	29.6	16.6
2020	January	138.2	30.3	19.02
	February	116.0	29.9	17.04
	March	51.3	30.1	16.04
	April	56.1	26.1	11.18
	May	144.8	21.7	8.42

Tmax = maximum temperature; Tmin = minimum temperature.

of grazing (leaf emergence rate, leaf elongation rate, and leaf life) are genetically determined and influenced by environmental variables, such as temperature, nutrient supply, and water supply to the plant, and by defoliation through induced changes in light interception (BARRE et al., 2015; GASTAL & LEMAIRE, 2015). Among these factors, water availability has an essential relationship with high yields in pasture production because it affects plant growth and regulates several physiological mechanisms of development (RAZA et al., 2019). Thus, when the water level is low, uptake and translocation are affected, and yields are compromised, as evidenced in the second agricultural year (Table 1).

The overseeding strategy resulted in a higher ($P < 0.05$) pasture height in the first crop year. These results can be explained by the fact that plants established together with soybeans obtained less solar radiation and thus lengthened their stems more in search of greater luminosity. However, there was no difference in pasture height between sowing strategies in the second agricultural year. The behavior of pasture height in response to water deficits was similar to that reported by (CHOUDHARY et al., 2020). The influence of water stress on sorghum and pearl millet crop growth was evaluated, and significant reductions in leaf blade growth of approximately 50 % when plants were grown under a low water supply were observed. The plants stand was more elevated ($P < 0.05$) under the no-tillage strategy (Table 2). The senescent leaves of the soybean crop fall on the ground, reducing seed-soil contact and exposing seeds to the environment, which causes more significant moisture loss, increased exposure to light and air, seedling death, and lower seed germination, thus leading to lower plant stands in the overseeding strategy (PACHECO et al., 2008). The lower plant stand in the second crop year is explained by water stress. Water acts as a universal solvent for the processes that govern plant physiology, from seed germination to the hydrolysis of reserve carbohydrates into soluble carbohydrates, affecting seed germination and the subsequent establishment of the pasture (ARAÚJO JÚNIOR et al., 2019).

In the second crop year, the no-tillage strategy resulted in a higher ($P < 0.05$) tiller density. However, there was no difference between treatments in the first crop year (Table 2). Forage plants have a compensatory effect on the growth and development of their tillers and can increase tiller density when there are fewer plants per area (VOLENEC & NELSON, 2020). The lower density of tillers in the overseeding strategy may be associated with more superficial plant roots, making it difficult to obtain water during the dry season.

Although, it produced smaller plant stands and less tillering, the overseeding strategy showed a higher ($P < 0.05$) pasture utilization period than the no-tillage strategy (Table 2). However, only in the

Table 2 - Average values over the successive measurements for pasture characteristics according to the year and seeding strategy.

Crop Year	Seeding strategy (SS)		Mean	CV (%)	*p - value*		
	OS	NTS			Year	SS	Y x SS
Pasture height (cm)							
2019	75.47^{Aa}	69.68^{Ab}	72.58				
2020	43.89^{Bb}	48.25^{Bb}	46.07	3.47	0.001	0.673	0.004
Mean	59.68	58.97	59.32				
Plants stand (plants m^{-2})							
2019	104.01	334.26	219.14^{A}				
2020	55.09	222.68	138.89^{B}	6.04	0.001	0.001	0.311
Mean	79.55^{b}	278.47^{a}	179.01				
Tiller density (tiller m^{-2})							
2019	555.56^{Aa}	547.75^{Aa}	549.66				
2020	118.06^{Bb}	244.44^{Ba}	181.25	21.36	0.001	0.069	0.001
Mean	336.81	394.10	365.45				
Period of pasture use (days)							
2019	92.00^{Aa}	60.00^{Bb}	76.00				
2020	70.00^{Ba}	50.00^{Bb}	60.00	4.43	0.001	0.001	0.001
Mean	81.00	55.00	68.00				
Forage production (ton of DM ha^{-1})							
2019	9.36^{Aa}	7.04^{Ab}	8.20				
2020	3.66^{Bb}	3.55^{Bb}	3.61	2.71	0.001	0.005	0.007
Mean	6.51	5.30	5.90				

first crop year was the foraged production higher ($P < 0.05$) for this overseeding strategy. As annual summer forages do not show growth during the winter period in southern Brazil, forage production anticipation is essential for pasture utilization and production. Therefore, the anticipation of forage production in the overseeding strategy was assigned to an earlier implementation (30 days) compared to those sown after the soybean harvest, which allowed a more extended pasture use.

Studies have shown that field-overseeding grain crops benefit soil and livestock, but their success depends on climate conditions (PARIZ et al., 2020; APFELBAUM et al., 2022). Other studies show that the overseeding of tropical forage species on the soybean crop does not affect the yield components or productivity of the grain crop (CRUSCIOL et al., 2014; ANDRADE et al., 2017). Aerial seeding, tractor-mounted airflow spreaders, and tractor-mounted broadcast spreaders are the main techniques currently used to overseed pastures in soybean culture (WILSON et al., 2019).

The Mesoregion of Southwest Paraná has an average annual precipitation of over 2000 millimeters (mm) distributed throughout the year, except in occasional periods of La Niña (CALDANA et al., 2019). This climatic characteristic suggests that overseeding tropical pastures over soybeans could be a viable strategy to reduce the autumn fodder shortage.

The transit of machinery to harvest soybeans does not impair the productivity of overgrown pastures. If there is adequate moisture and management, the timing of harvesting coincides with the beginning of the vegetative phase of the pasture. This minimizes plant mortality and loss of leaf area due to harvesting operations, a fact associated with plant height and the proximity of the apical meristem to the soil. Furthermore, the suffocating effect of soybean stubble is minimal since the amount resulting from this process is not expressive (< 2000 kg ha^{-1}) (ANDRADE et al., 2017).

Pasture height, utilization period, and forage production did not differ ($P > 0.05$) among the forage species (Table 3). These results agreed with the literature since similar forage yields are common among these forage species when subjected to defoliation management (PACHECO et al., 2014; COMASSETO et al., 2020). However, pearl millet pasture had a higher ($P = 0.009$) plant stand. Pearl millet plants have a larger stand than other tropical forage species in overseeding strategies because they

Table 3 - Average values over the successive measurements for pasture characteristics according to forage species.

Variables	------------------Forage species-----------------		--------CV (%)--------	--------*p - value*-------
	Pearl millet	Sudangrass		
Pasture height (cm)	58.02	60.62	3.47	0.132
Plant stand (plants m^{-2})	204.47[a]	153.54[b]	6.04	0.009
Tiller density (tiller m^{-2})	331.01[b]	399.88[a]	21.36	0.033
Period of pasture use (days)	68.00	68.00	4.43	1.000
Forage production (ton of DM ha^{-1})	6.20	5.61	2.71	0.152

CV = coefficient of variation. Means followed by different lowercase letters differ significantly ($P < 0.05$) according to the F-test.

have a reduced seed size, which provides a larger specific surface for seed contact with the soil, favoring germination (PACHECO et al., 2008). In addition, according to these researchers, the high emergence speed of pearl millet plants compared to other tropical forage species has made this species one of the most suitable for overseeding soybean crops.

The sudangrass pasture had a higher ($P = 0.033$) tiller density (Table 3). The lower density of the sudangrass pasture favored tillering because the emission of tillers is an expected physiological response to the greater availability of resources, mainly solar radiation (MATTHEW et al., 1995). Furthermore, sudangrass has a greater genetic capacity for tillering than pearl millet (SILUNGWE et al., 2010). However, this may be related to the cultivars used.

CONCLUSION

The overseeding of pearl millet or sudangrass in the full seed stage of the soybean crop is efficient in supplying forage in the autumn forage shortage period in ICLS, and its success depends on the climate conditions.

The overseeding strategy increased the pasture utilization period and forage production, which is ideal for starting the herd earlier in the field and animal production increase.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. In addition, all authors critically revised the manuscript and approved the final version.

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