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Crop Science/ Original Article

Agronomic performance of soybean in succession to off-season pastures with *Urochloa* mixes

Abstract – The objective of this work was to evaluate the agronomic performance of soybean in succession to off-season pastures with *Urochloa* mixes, in sandy soil. The experiment was carried out in a sandy Oxisol, located in the municipality of Caiuá, in the state of São Paulo, Brazil, in a randomized complete block design, with four replicates. The 2020/2021, 2021/2022, and 2022/2023 harvests were evaluated in the following systems: off-season pasture of *Urochloa ruziziensis*, off-season pasture of 'BRS Paiaguás' *Urochloa brizantha*, off-season pasture of 50% *U. ruziziensis* and 50% 'BRS Paiaguás' *U. brizantha*, off-season pasture of 67% *U. ruziziensis* and 33% 'BRS Paiaguás' *U. brizantha*, fallow under no-tillage, and fallow under conventional tillage (harrowing). Pods per plant, grains per pod, grains per plant, and grain mass did not differ between the systems. Plant height and cumulative yield over three years stood out in the systems with BRS Paiaguás and the mixes with *U. ruziziensis*. The agronomic performance of soybean cultivated in sandy soil is benefited by the previous use of off-season pastures, with similar effects between pastures of *U. ruziziensis* and 'BRS Paiaguás' *U. brizantha* exclusively or mixed in different proportions.

Index terms: *Glycine max*, Brachiaria, grass mixture, integrated crop-livestock system, off-season cattle.

Desempenho agronômico de soja em sucessão a pastos safrinha com misturas de *Urochloa*

Resumo – O objetivo deste trabalho foi avaliar o desempenho agronômico da soja em sucessão a pastos safrinha com misturas de *Urochloa*, em solo arenoso. O experimento foi conduzido em Latossolo Amarelo distrófico de textura arenosa, localizado no município de Caiuá, no estado de São Paulo, Brazil, em delineamento experimental de blocos ao acaso, com quatro repetições. As safras de 2020/2021, 2021/2022 e 2022/2023 foram avaliadas nos seguintes sistemas: pasto safrinha de *Urochloa ruziziensis*, pasto safrinha de *Urochloa brizantha* 'BRS Paiaguás', pasto safrinha de 50% de *U. ruziziensis* e 50% de *U. brizantha* 'BRS Paiaguás', pasto safrinha de 67% de *U. ruziziensis* e 33% de *U. brizantha* 'BRS Paiaguás', pousio com semeadura direta e pousio com preparo convencional do solo. Número de vagens por planta, grãos por vagens, grãos por planta e massa de grãos não diferiram entre os sistemas. Altura de plantas e produtividade acumulada em três anos se destacaram nos sistemas com BRS Paiaguás e nas misturas com *U. ruziziensis*. O desempenho agronômico da soja cultivada em solo arenoso é beneficiado pelo uso prévio de pastos safrinha, tendo apresentado efeitos semelhantes entre os pastos de *U. ruziziensis* e *U. brizantha* 'BRS Paiaguás' exclusivos ou misturados em diferentes proporções.

Termos para indexação: *Glycine max*, Braquiaria, mistura de capins, sistema de integração lavoura-pecuária, boi safrinha.

Introduction

The use of integrated crop-livestock systems (ICLSs) has allowed of the expansion of soybean [*Glycine max* (L). Merr.] cultivation in critical regions due to the development of no-tillage systems, especially in sandy soil areas, where the benefits of straw become essential to ensure crop productivity (Fagundes et al., 2019).

Among such systems, off-season pastures, also called off-season cattle system, stand out, with cattle production based on the use of the forage accumulated in the off-season period, with soybean cultivation in succession under no-tillage (Vilela et al., 2011, 2017). To increase the efficiency of these systems, the effects of the seasonality of grass production in the dry season should be reduced. For this, grass mixtures are an alternative, based on the complementarity between species (Barbosa et al., 2018). The aim is mixing compatible forages, with different productive characteristics, to act during different periods, in order to reach a greater forage efficiency and distribution throughout the grazing cycle.

The most widely used forage in ICLS systems is Congo grass [*Urochloa ruziziensis* (R.Germ. & C.M.Evrard) Crins] due to its rapid initial growth, excellent soil coverage, and ease of desiccation in the no-tillage system (Grigolli et al., 2017). More recently, the BRS Paiaguás *Urochloa brizantha* (A.Rich.) R.D.Webster cultivar has been highlighted for its greater forage accumulation, high percentage of leaves, and greater nutritional value in dry periods (Valle et al., 2013).

The association between those two grasses in off-season pastures generates the hypothesis of a more stable grazing period in terms of forage quantity and quality. However, the dynamics of each species in an attempt to maintain stable pasture conditions can directly reflect on forage production and straw accumulation in the no-tillage system, with consequent effects on the soil (Barbosa et al., 2018).

The objective of this work was to evaluate the agronomic performance of soybean in succession to off-season pastures with *Urochloa* mixes, in sandy soil.

Materials and Methods

The experiment was carried out in the municipality of Caiuá, in the state of São Paulo, Brazil (21°49'54"S, 51°59'54"W, at 330 m altitude). According to Köppen-Geiger's classification, the climate is Aw, tropical, with a dry winter and a hot and rainy summer. The soil type is a Latossolo Amarelo Distrófico arenoso (Santos et al., 2018), equivalent to a sandy Oxisol, with an average clay content of 110 g kg^{-1} in 0 to 0.20 m layer and chemical attributes presented in Table 1.

The experimental design was in randomized complete blocks, in a 3x6 factorial arrangement (three harvests x six systems), with four replicates. The 2020/2021, 2021/2022, and 2022/2023 harvests were evaluated in the following systems: off-season pasture of *U. ruziziensis*, off-season pasture of 'BRS Paiaguás' *U. brizantha*, off-season pasture of 50% *U. ruziziensis* and 50% 'BRS Paiaguás' *U. brizantha* (50:50 mix), off-season pasture of 67% *U. ruziziensis* and 33% 'BRS Paiaguás' *U. brizantha* (67:33 mix), fallow in the off-season under no-tillage, and fallow in the off-season under conventional tillage (harrowing). The average area for each replicate was 2.0 ha.

The first four treatments were carried out under a no-tillage system using straw from off-season pastures. In the fifth treatment, the no-tillage system used weed residue and soybean residue from the previous harvest. In the sixth treatment, soil preparation consisted of harrowing prior to soybean sowing.

In the 2020/2021 harvest, rainfall during the experimental period was 848 mm, better distributed and more concentrated in December and January (Figure 1 A), matching the soybean grain-filling stage. The minimum, average, and maximum temperatures were 22.4, 27.7, and 33.0°C, respectively.

In the 2021/2022 harvest, rainfall was 812 mm, with irregular rainfall and better concentration in the second half of January 2022, but without rainfall in the first half of November and December (Figure 1 B), coinciding with the vegetative-growth and flowering stages of soybean. Minimum, average, and maximum temperatures were 22.6, 28.2, and 33.9°C, respectively.

In the 2022/2023 harvest, total rainfall was 957 mm, with a low regularity in November and a low precipitation in December, especially in the second half of the month, considered the period of soybean pod formation. The minimum, average, and maximum temperatures were 21.0, 26.3, and 31.5°C, respectively.

Primary activities in the experimental area began after the cultivation of 'NS6700IPRO' soybean in the 2015/2016 harvest, when 'DKB 390PRO2' corn (*Zea mays* L.) was sown associated with *U. ruziziensis*, 'BRS Paiaguás' *U. brizantha*, and 'BRS Piatã' *U. brizantha*, with soybean in succession in the 2016/2017, 2017/2018, and 2018/2019 harvests, followed by off-season pastures of *U. ruziziensis*, 'BRS Paiaguás' *U. brizantha*, and 'BRS Zuri' *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs, without corn cultivation in 2019, but with soybean in the 2019/2020 harvest. Fertilization was carried out only on the grain crops, following the recommendations of Raij et al. (1997).

To establish the treatments of the experiment, the grasses were sown after soybean harvest in March 2020, either exclusively or mixed, in rows spaced at 0.45 m, using 10 kg ha^{-1} coated seeds with 80% crop value.

In 2020, the pasture was sown on March 29 and 30 after 66 days of grazing, when rainfall was 479 mm and average temperature was 24.3ºC. In 2021, sowing was carried out from March 8 to 10, with 65 days of grazing, accumulated rainfall of 231 mm, average temperature of 24.7ºC, and two intense frosts on June 30 and July 30. In 2022, pastures were sown from February 26 to 28, with 134 days of grazing, 481 mm rainfall, and 24.5ºC average temperature.

The grazing method was continuous with a variable stocking rate, based on the put-and-take technique (Mott & Lucas, 1952). The aim was to maintain target pasture height at 0.30 m (Euclides et al., 2016), using Nellore cattle with an average weight of 220 kg and an average age of 8 months. At the end of the grazing period, the grasses were desiccated using glyphosate (1,520 g a.i. ha^{-1}). Afterwards, '64I61RSF IPRO' soybean was sown in rows spaced at 0.45 m, using a seeder with a shaft-type furrowing mechanism, with 14 seeds per meter at a depth of 4.0 to 7.0 cm. The seeds were co-inoculated with the AbV5 and AbV6 *Azospirillum brasilense* strains at 9 $\times 10^8$ CFU mL^{-1} (10 mL kg^{-1}) and the SEMIA 5079 *Bradyrhizobium japonicum* strain at 5×10^9 CFU g^{-1} (5.0 mL kg^{-1}).

In the 2020/2021 harvest, soybean was sown on October 25 and 26 of 2020, with 240 kg ha^{-1} 06-38-10 (14.4 kg ha^{-1} nitrogen, 91.2 kg ha^{-1} P_2O_5, and 24 kg ha^{-1} K_2O). At the end of December, 85 kg ha^{-1} potassium chloride (51 kg ha^{-1} K_2O) were applied. Harvesting was carried out on March 9 and 10 of 2021, 135 days after sowing.

In 2021/2022, crop sowing was performed on October 15 and 17 of 2021, with 90 kg ha^{-1} 09-48-00 (8.0 kg ha^{-1} nitrogen and 43 kg ha^{-1} P_2O_5). Complementary fertilization consisted of 172 kg ha^{-1} potassium chloride (103 kg ha^{-1} K_2O) in the first week of December 2021. Harvesting occurred on February 22 and 23 of 2022, 129 days after sowing.

In 2022/2023, soybean was sown on October 19 and 20 of 2022, with 92 kg ha^{-1} 09-48-00 (8.0 kg ha^{-1} nitrogen and 44 kg ha^{-1} P_2O_5). Complementary fertilization was performed with 127 kg ha^{-1} potassium chloride (76 kg ha^{-1} K_2O), applied in the second week of December 2022. Harvesting was carried out on March 9 and 10 of 2023, 139 days after sowing.

Table 1. Soil chemical attributes in the experimental area, located in the municipality of Caiuá, in the state of São Paulo, Brazil[(1)].

Layer (m)	pH H_2O	P_{resin}	$S\text{-}SO_4$	OM	K	Ca	Mg	H+Al	Al	SB	CEC	V	m
		-----(mg dm^{-3})-----		(g dm^{-3})	----------(mmol$_c$ dm^{-3})----------							-----(%)-----	
2020/2021 harvest													
0.00–0.10	5.4	25.3	2.9	17.1	1.9	11.5	7.3	17.7	0.7	20.8	38.7	53.4	3.7
0.10–0.20	5.2	21.4	1.7	14.5	1.7	12.1	6.1	16.8	0.9	20.0	36.7	53.1	4.9
0.20–0.40	5.1	9.4	2	12.4	1.4	10.0	3.9	16.1	1.2	15.3	31.4	48.9	7.1
2021/2022 harvest													
0.00–0.10	5.5	52.7	5.4	16.9	2.6	25.9	14.2	18.3	0	42.6	60.9	69.3	0
0.10–0.20	5.3	57.6	4.4	13.9	2.3	21.1	10.1	20.3	0.7	33.4	53.8	61.3	2.3
0.20–0.40	5.2	26.3	4.7	11.7	2.0	14.3	6.2	20.3	1.7	22.5	42.7	53.0	5.7
2022/2023 harvest													
0.00–0.10	5.6	40.5	2.9	17.8	2.2	16.2	11.4	13.3	0	29.8	43.1	67.4	0.2
0.10–0.20	5.4	37.7	2.7	14.7	2.1	11.6	7.9	14.0	0.2	21.6	35.6	59.8	0.9
0.20–0.40	5.2	23.5	2.6	12.7	1.7	9.1	5.3	14.2	0.6	16.2	30.4	53.0	3.9

[(1)]OM, organic matter; H+Al, potential acidity; SB, sum of Ca-Mg-K; CEC, cation exchange capacity; V, Ca-Mg-K saturation; and m, aluminum saturation.

Pest and disease control was carried out as needed, following technical recommendations (Seixas et al., 2020).

The evaluated soybean traits were: final plant stand, plant height, first pod height, pods per plant, grains per pod, grains per plant, empty pods, grain mass, and grain yield after complete crop maturation.

Six random points were sampled per plot, consisting of four parallel lines of 2.5 m in length (4.5 m^2). After being counted, the plants were removed to determine the production components of ten random plants per sample. Then, mechanical extraction and weighing were carried out to obtain the moisture content of the grains of the total sample, standardized at 13% moisture, in order to evaluate grain mass and grain yield.

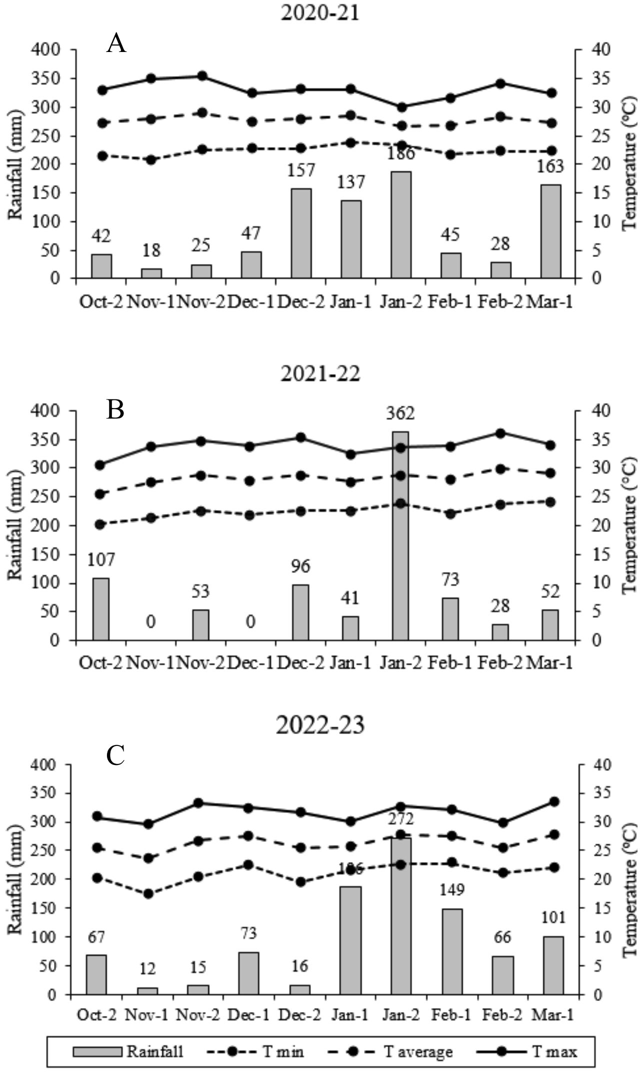

Figure 1. Minimum (Tmin), average (Taverage), and maximum (Tmax) temperatures, as well as rainfall, registered every 15 days during the experimental period in the 2020/2021 (A), 2021202 (B), and 2022/2023 (C) harvests in the municipality of Caiuá, in the state of São Paulo, Brazil.

Straw mass was measured before soybean cultivation, by cutting the forage material delimited by a 0.5 m^2 metal frame at nine points in each plot. The samples were weighed and placed in an oven with forced-air circulation, at 65°C, for 72 hours to determine dry matter content, which was extrapolated to the value of the total green sample.

The data were subjected to the analysis of variance using the F-test, and means were compared by Tukey's test, at 5% probability. The interaction between systems and harvests was analyzed using the PROC Mixed procedure, considering random block effects and fixed effects of crop systems, in which a repeated statement was used with harvest specified as the repeated variable. Statistical analyses were performed using the SAS software (SAS Institute Inc., Cary, NC, USA).

Results and Discussion

Straw mass varied in the study years. In the 2021/2022 harvest, the values obtained for the variable were lower for the off-season pastures regardless of the evaluated systems (Table 2). In the other harvests, straw mass was similar among the off-season pastures, being above 5.4 Mg ha^{-1}. This variation was due to the climatic conditions imposed on the pastures throughout the harvests. In 2020, the accumulated rainfall was 479 mm during the off-season pasture period, but was 231 mm in 2021 and 481 mm in 2022. This means that, in 2021, the pasture only received 48% of the rainfall volume of the other years, in addition to being affected by two frosts, which reduced the accumulation of forage and straw mass left on the no-tillage system.

Regarding systems, straw mass was similar among *U. ruziziensis*, 'BRS Paiaguás' *U. brizantha*, and the 50:50 mix. However, 'BRS Paiaguás' *U. brizantha* showed a greater straw mass than the 67:33 mix. This is an indicative that the balance between the grass proportions used in the mix is an essential factor, determining not only pasture production, but also the amount of straw left for no-tillage cultivation.

Final plant stand was higher in the two first harvests (2020/2021 and 2021/2022) compared with the subsequent one (2022/2023), showing an increase of 30 and 39%, respectively, in plant population (Table 3).

Regardless of the harvests, the cropping systems with *Urochloa* spp. straw resulted in a higher plant stand than those with fallow under no-tillage and under conventional tillage. In addition, plant stand in the systems with both *U. ruziziensis* and 'BRS Paiaguás' *U. brizantha* mixes (50:50 and 67:33) was similar to that in the systems with each forage exclusively.

A significant reduction of 17 and 30% was observed in plant stand in fallow under no-tillage sowing and under conventional tillage in the absence of straw combined with soil disturbance. According to Corassa et al. (2018), the limit for plant stand reduction is 18% in high-productivity environments, without penalizing yields, but only 10% in low-productivity ones. Although reductions in plant stand in fallow systems can contribute to the spatial adaptation of the crop, benefiting other production components (Balbinot Junior et al., 2015), the grain productivity lost due to a decreased number of plants producing grains may not be compensated.

Plant height was much higher in the 2020/2021 and 2022/2023 harvests than in 2021/2022. This could be explained by the fact that, in the first and third harvests, there was a better distribution of rainfall, with slightly milder temperatures. Moreover, in the second harvest, rainfall distribution was completely irregular (Figure 1 B), with a severe water deficit in the vegetative stage of soybean, which, coupled with high temperatures, led to an earlier accumulation of growing degree days and, consequently, to an early flowering, affecting the vegetative development of the plants, mainly in height.

As to the systems, plant height was higher in the treatments with *Urochloa* spp. straw compared with those with fallow. The exception was *U. ruziziensis*, whose values were similar to those of the fallow systems, showing the positive effects of 'BRS Paiaguás' *U. brizantha* and the grass mixes on plant height. According to Chaveiro et al. (2022), straw as soil coverage helps plant growth by nutrient cycling, maintaining a milder soil temperature, and reducing water loss through evaporation.

First pod height was lower in the 2021/2022 harvest due to the same reasons that influenced plant height (Table 3). This variable showed lower values in fallow under no-tillage and under conventional tillage when compared with the systems with *Urochloa* spp. straw. Ribeiro et al. (2017) concluded that an increase in first pod height may be unfavorable since a lower stem exploration (long internodes and less nodes where flowering occurs), that is, a larger portion of the stem (internodes) without pods, may cause a reduction in plant potential.

The number of pods per plant was higher in the first harvest (Table 4), followed by the third harvest. In the second harvest, there was a reduction of 65% in this variable, which was one of the main

Table 2. Straw mass of off-season pastures prior to soybean (*Glycine max*) cultivation in the municipality of Caiuá, in the state of São Paulo, Brazil[1].

System	Harvest			Mean
	2020/2021	2021/2022	2022/2023	
	Straw mass (kg dry matter per hectare)			
Urochloa ruziziensis	5,643	995	4,938	3,858ab
'BRS Paiaguás' *Urochloa brizantha*	6,170	1,150	6,037	4,452a
50:50 mix	5,626	1,359	5,921	4,302ab
67:33 mix	5,124	1,357	4,859	3,780b
Mean	5,641A	1,215B	5,437A	
	Analysis of variance (p>F)			
Systems (S)	0.0352			
Harvests (H)	<0.0001			
SxH interaction	0.2374			
Coefficient of variation (%)	22.5			

[1]Means followed by different letters differ by Tukey's test, at 5% probability. Lowercase letters compare systems between rows, and uppercase letters, harvests between columns.

factors explaining the observed drop in grain yield. The climatic conditions in the 2021/2022 harvest (Figure 1 B), associated to the lower straw mass due to the effect of frosts, were unfavorable for the formation and setting of soybean pods. Cortez et al. (2015) concluded that, although climatic stresses, such as water deficit during flowering and grain filling, cause damage to pod formation, the presence of straw as soil coverage reduces the rate of water evaporation and soil heating, minimizing the stress of plants during their development. No significant differences, however, were found for pods per plant between the *Urochloa* spp. straw, mixes, and fallow systems.

In the first and third harvests, the soybean reproductive period was favored by a better regularity and concentration of rainfall in December and January (Figure 1 A), with slightly milder temperatures. However, the crop was not favored in the intermediate harvest of 2021/2022 due to the super concentration of rainfall in the second half of January 2022 and to the absence of rain in the first half of December (Figure 1 B), with higher temperatures in the soybean flowering stage. In terms of climatic conditions, the reproductive stage is the most important for plant grain production since the highest water demand by soybean occurs during the flowering/grain-filling period (Nunes et al., 2021), which explains why water deficit during pod

Table 3. Final plant stand, plant height, and first pod insertion height of soybean (*Glycine max*) in succession to off-season pastures with *Urochloa* spp. mixes and fallow in the municipality of Caiuá, in the state of São Paulo, Brazil[(1)].

System	Harvest			Mean
	2020/2021	2021/2022	2022/2023	
	Final plant stand (thousand plants per hectare)			
Urochloa ruziziensis	229.2	238.8	183.6	217.2a
'BRS Paiaguás' *Urochloa brizantha*	204.4	244.9	176.5	208.6a
50:50 mix	223.5	237.9	186.5	216.0a
67:33 mix	230.0	231.2	182.7	214.6a
Fallow under no-tillage	213.9	199.6	122.8	178.8b
Fallow under conventional tillage	154.2	185.0	110.5	149.9c
Mean	209.2A	222.9A	160.4B	217.2
	Plant height (cm)			
U. ruziziensis	92.3	55.7	89.0	79.0b
'BRS Paiaguás' *U. brizantha*	100.8	58.6	99.6	86.3a
50:50 mix	103.0	61.0	98.4	87.5a
67:33 mix	102.6	58.7	91.4	84.3a
Fallow under no-tillage	97.4	50.0	92.2	79.9ab
Fallow under conventional tillage	89.5	45.9	84.8	73.4b
Mean	97.6A	55.0C	92.6B	81.7
	First pod insertion height (cm)			
U. ruziziensis	16.4	13.0	20.4	16.6a
'BRS Paiaguás' *U. brizantha*	17.2	14.1	23.8	18.4a
50:50 mix	18.6	14.6	24.2	19.1a
67:33 mix	18.5	14.0	23.8	18.8a
Fallow under no-tillage	15.8	12.8	20.4	16.3b
Fallow under conventional tillage	13.8	12.5	17.9	14.7b
Mean	16.7B	13.5C	21.7A	17.3

Source of variation	Analysis of variance (p>F)		
	Final plant stand	Plant height	First pod insertion height
Systems (S)	<0.0001	<0.0001	<0.0001
Harvests (H)	<0.0001	<0.0001	<0.0001
SxH interaction	0.2264	0.8695	0.7556
Coefficient of variation (%)	21.7	25.4	25.0

[(1)]Means followed by different letters differ by Tukey's test, at 5% probability. Lowercase letters compare systems between rows, and uppercase letters, harvests between columns.

formation becomes much more harmful than in the initial vegetative stages (Silva et al., 2018).

Grains per pod did not differ between the systems (Table 4), being higher only in the 2021/2022 harvest. This lack of change in the number of grains per pod is, in most cases, expected because of the intrinsic genetic factors of the cultivar, considered constant due to genetic improvement (Bulegon et al., 2016).

The percentage of empty pods in relation to the total number of pods showed there was an interaction between systems and harvests. The amount of empty pods was higher in fallow under no-tillage and under conventional tillage in the first harvest, emphasizing the negative effect of systems without straw on pod set and formation. In the following harvest, the highest percentage of empty pods occurred in fallow under conventional tillage, with values similar to those of the *Urochloa* spp. treatments and higher than those of fallow under no-tillage. In the last harvest, *U. ruziziensis* and the 50:50 mix provided a lower amount of empty pods than 'BRS Paiaguás' *U. brizantha*, the 67:33 mix, and the fallow treatments.

The number of grains per plant was higher in the 2020/2021 harvest, followed by the 2022/2023 and

Table 4. Number of pods per plant, grains per pod, and empty pods of soybean (*Glycine max*) in succession to off-season pastures with *Urochloa* spp. mixes and fallow in the municipality of Caiuá, in the state of São Paulo, Brazil[(1)].

System	Harvest			Mean
	2020/2021	2021/2022	2022/2023	
		Pods per plant (unit)		
Urochloa ruziziensis	134.1	52.6	79.0	88.6
'BRS Paiaguás' *Urochloa brizantha*	153.3	50.1	94.9	99.5
50:50 mix	129.8	54.9	85.5	90.1
67:33 mix	134.1	51.3	80.1	88.5
Fallow under no-tillage	140.1	44.8	87.2	90.7
Fallow under conventional tillage	151.1	42.9	94.2	96.1
Mean	140.4A	49.4C	86.8B	92.2
		Grains per pod (unit)		
U. ruziziensis	2.2	2.4	2.2	2.3
'BRS Paiaguás' *U. brizantha*	2.2	2.4	2.2	2.3
50:50 mix	2.2	2.4	2.2	2.3
67:33 mix	2.2	2.3	2.2	2.3
Fallow under no-tillage	2.0	2.4	2.1	2.2
Fallow under conventional tillage	2.1	2.4	2.1	2.2
Mean	2.1B	2.4A	2.2B	2.2
		Empty pods (%)		
U. ruziziensis	3.3bA	2.9abA	0.9bB	2.4
'BRS Paiaguás' *U. brizantha*	3.3bA	2.5abAB	1.5aB	2.4
50:50 mix	3.4bA	2.5abB	0.7bB	2.4
67:33 mix	2.7bA	2.4aA	1.2aA	2.1
Fallow under no-tillage	4.2aA	2.1bB	1.4aC	2.6
Fallow under conventional tillage	3.9aA	2.9abAB	1.2aB	2.6
Mean	3.4	2.5	1.1	2.3

Source of variation	Analysis of variance (p>F)		
	Pods per plant	Grains per pod	Empty pods
Systems (S)	0.2037	0.1228	0.6617
Harvests (H)	<0.0001	0.0002	<0.0001
SxH interaction	0.2808	0.3024	0.0027
Coefficient of variation (%)	43.2	5.8	51.1

[(1)]Means followed by different letters differ by Tukey test's, at 5% probability. Lowercase letters compare systems between rows, and uppercase letters, harvests between columns.

2021/2022 harvests (Table 5). These results are most likely linked to the higher number of pods per plant since the amount of grains per pod were lower in these harvests (Table 4). Grains per plant encompass variations in pods per plant, grains per pod, and empty pods, showing the total grain production per plant, being directly linked to pods per plant. Therefore, the much higher number of pods per plant in the 2020/2021 harvest offset the effects of a lower amount of grains per pod, resulting in a higher number of grains per plant.

Grain mass showed there was an interaction between the evaluated systems and harvests. In 2020/2021 and 2022/2023, higher values were found in fallow under no-tillage and conventional tillage as a consequence of the lower final plant stand, which allows of a greater plant development with a greater grain filling. However, in the 2021/2022 harvest, grain mass did not differ between systems.

Although there were several moments of water deficit during soybean development in the 2021/2022 harvest (Figure 1 B), the grain-filling stage occurred under favorable precipitation conditions. These conditions and a lower number of pods per plant as a source of self-competition, allowed of soybean to concentrate photoassimilates for a better grain establishment and filling, leading to the production of larger and heavier grains. However, in the first harvest, with more than twice as many pods (Table 4), favorable weather conditions were not able to support the requirement to be filled for pods per plant, resulting in a lower grain mass (Table 5). Contrastingly, in the third harvest, the lower final plant stand (Table 3), coupled with favorable filling conditions (Figure 1 C), provided a higher grain mass.

Grain yield in 2020/2021 and 2022/2023 was higher than in the 2021/2022 harvest due to the lower amount of pods per plant and grains per plant (Table 6). The climate scenario in the second year (Figure 1 B),

Table 5. Number of grains per plant and grain mass of soybean (*Glycine max*) in succession to off-season pastures with *Urochloa* spp. mixes and fallow in the municipality of Caiuá, in the state of São Paulo, Brazil[(1)].

System	Harvest			Mean
	2020/2021	2021/2022	2022/2023	
		Grains per plant (unit)		
Urochloa ruziziensis	295.6	125.4	177.9	199.6
'BRS Paiaguás' *U. brizantha*	336.6	123.3	215.2	225.0
50:50 mix	287.9	132.9	192.6	204.5
67:33 mix	303.1	121.5	181.6	202.0
Fallow under no-tillage	290.4	110.2	184.2	194.9
Fallow under conventional tillage	319.6	102.5	189.1	203.7
Mean	305.5A	119.3C	190.1B	205.0
		Grain mass (g 100 per grains)		
U. ruziziensis	12.3bB	16.3aA	17.7abA	15.4
'BRS Paiaguás' *U. brizantha*	11.9bB	16.5aA	17.7abA	15.3
50:50 mix	12.0bC	16.0aB	18.0abA	15.3
67:33 mix	12.4b	17.1aA	17.3bA	15.6
Fallow under no-tillage	14.1a	17.0aB	20.3aA	17.1
Fallow under conventional tillage	13.2ab	17.0aB	19.0aA	16.4
Mean	12.7	16.6	18.3	15.9

Source of variation	Analysis of variance (p>F)	
	Grains per plant	Grain mass
Systems (S)	0.1702	<0.0001
Harvests (H)	<0.0001	<0.0001
SxH interaction	0.5956	0.0108
Coefficient of variation (%)	40.1	16.3

[(1)]Means followed by different letters differ by Tukey's test, at 5% probability. Lowercase letters compare systems between rows, and uppercase letters, harvests between columns.

associated to a lower straw layer (Table 2), resulted in losses in crop development.

Regarding the evaluated systems, grain yield was higher for soybean grown in succession to *Urochloa* spp. straw systems than in fallow under no-tillage and conventional tillage. Furthermore, grain yield showed similar values in the systems with both mixes of *U. ruziziensis* with 'BRS Paiaguás' *U. brizantha* and in those with *U. ruziziensis* or 'BRS Paiaguás' *U. brizantha* exclusively.

According to Silva et al. (2018), soybean grain yield is limited by source-sink regulations. Although soybean subjected to water deficit during the reproductive stage shows a greater accumulation of reserves in leaves and stems, the intense processes of pod formation and grain filling increase plant demand (sink) for higher levels than the produced photoassimilates (source). To maintain their production under an appropriate source-sink relationship, soybean plants can adjust their production components according to variations in plant density, associated to final plant stand and plant height. In this line, Ribeiro et al. (2020) observed that high plant densities lead to a decrease in the number of branches and a low rate of flower-bud fixation, with a consequent reduction in pods per plant.

Average grain yield was similar between fallow under no-tillage and conventional tillage. However, for fallow under conventional tillage, this variable showed the greatest differences in relation to the off-season pastures with *Urochloa* spp. The differences, corresponding to 609 kg ha^{-1}, when compared with the grass mixes, and to 518 kg ha^{-1}, when compared with *Urochloa* spp. exclusively, are attributed to the cover provided by the forages and the degrading processes resulting from constant soil disturbance. Among these processes are the reduction in carbon aggregation and accumulation in the soil and acceleration of organic matter decomposition, in addition to an increased soil density and resistance to penetration in the subsurface (Sales et al., 2016).

Balbinot Junior et al. (2017), when comparing the effect of *U. ruziziensis* and 'BRS Piatã' *U. brizantha* with that of a fallow system on soybean performance in succession, obtained grain yields of 2,087, 3,823, and 3,720 kg ha^{-1} for the fallow system, *U. ruziziensis*, and 'BRS Piatã' *U. brizantha*, respectively. The authors concluded that the higher grain yield in the systems with *Urochloa* spp. are due not only to straw mass as soil coverage, but also to the effect of the roots that grasses introduce into the soil, whose physical quality is improved, with increased infiltration and water

Table 6. Grain yield and accumulated grain yield of soybean (*Glycine max*) in succession to off-season pastures with *Urochloa* spp. mixes and fallow in the municipality of Caiuá, in the state of São Paulo, Brazil[(1)].

System	Harvest			Mean	Accumulated grain yield (kg ha^{-1})
	2020/2021	2021/2022	2022/2023		
	Grain yield (kg ha^{-1})				
Urochloa ruziziensis	3,754	2,346	3,728	3,276a	9,828ab
'BRS Paiaguás' *Urochloa brizantha*	3,612	2,337	3,981	3,310a	9,930a
50:50 mix	3,809	2,347	4,122	3,426a	10,277a
67:33 mix	3,932	2,284	3,808	3,342a	10,025a
Fallow under no-tillage	3,618	1,856	3,458	2,977b	8,932b
Fallow under conventional tillage	3,540	1,507	3,278	2,775b	8,326b
Mean	3,711A	2,113B	3,729A		9,553
Source of variation	Analysis of variance (p>F)				
	Grain yield			Accumulated grain yield	
Systems (S)	<0.0001			<0.0001	
Harvests (H)	<0.0001			-	
SxH interaction	0.1565			-	
Coefficient of variation (%)	26.4			8.29	

[(1)]Means followed by different letters differ by Tukey’s test, at 5% probability. Lowercase letters compare systems between rows, and uppercase letters, harvests between columns.

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retention, better oxygen flow, and increased phosphorus availability for the plants (Merlin et al., 2013).

Fabris et al. (2018), studying the impact of straw input on soybean yield in succession in western São Paulo, obtained grain yields of 4,051 and 1,367 kg ha^{-1} when the straw mass of *U. ruziziensis* was 2,313 kg ha^{-1} in the 2014/2015 harvest and of 927 kg ha^{-1} in the 2015/2016 harvest, respectively. The authors also highlighted the risk of interferences on crop productivity caused by the irregular distribution of summer rainfall and the occurrences of dry spells in the western region of the state.

Analyzing accumulated grain yield, which is the sum of the grain yield from the three harvests, it is possible to observe more precisely the impact of the treatments over the years (Table 6), in which the negative effects of fallow on grain yield appear to be even more evident. Compared with the systems with straw in the three experimental years, grain yield losses were 1,083 kg ha^{-1} (18 bags per hectare) in the no-tillage systems without *Urochloa* spp. straw, reaching 1,689 kg ha^{-1} under soil disturbance in conventional tillage.

The mixes presented better results than each grass exclusively, but did not differ significantly from U. *ruziziensis*, which is the most common forage of off-season pastures. This was the case for accumulated grain yield, which did not differ between both mixes and U. *ruziziensis* (p=0.7847 and p=0.0857, respectively). Despite this, soybean yield increased in 197 kg ha^{-1} more after the use of the 67:33 mix and in 449 kg ha^{-1} after that of the 50:50 mix, which showed the highest accumulated grain yield in the three years, surpassing *U. ruziziensis* exclusively.

The obtained results are a reflection not only of the total amount of straw accumulated by the mixes, which provide excellent soil coverage, but also of other possible effects, mainly on the physical, chemical, and biological attributes of the soil, including nutrient cycling that tends to provide a more favorable environment for plant development.

Conclusion

The agronomic performance of soybean (*Glycine max*) cultivated in sandy soil is benefited by the previous use of off-season pastures, with similar effects observed between treatments with *Urochloa ruziziensis* or 'BRS Paiaguás' *Urochloa brizantha* exclusively or mixed in different proportions.

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