Soybean performance in succession to the intercropping of corn with marandu grass and pigeonpea in an integrated agricultural production system[1]

Roseana Ramos Pereira[2], Izabela Militão Garcia[2], Viviane Cristina Modesto[2], Bianca Midori Souza Sekiya[2], Deyvison de Asevedo Soares[2], Marcelo Andreotti[2]*

10.1590/0034-737X202370030008

ABSTRACT

Integrated agricultural production systems have been improved with the introduction of *Urochloa* grasses aiming at obtaining straw for a no-tillage system (NTS) and the increase of legumes, which promote physicochemical improvements in soils and guarantee intensification and sustainability of production. This study aimed to evaluate the agronomic traits and yield of soybean in succession to the intercropping of corn with marandu grass and/or pigeonpea in five populations of plants harvested for silage production. The experiment was carried out in the Cerrado region of Selvíria, MS, Brazil, during the 2016/17 and 2017/18 agricultural years, in an Oxisol. The experimental design consisted of randomized blocks, with four replications. The treatments were arranged in a 2×5 factorial scheme, consisting of off-season corn intercropped with pigeonpea (*Cajanus cajan* (L.) Millsp.) and off-season corn intercropped with marandu grass (*Urochloa brizantha*) and pigeonpea, in addition to five sowing densities (0, 6, 12, 18, and 24 seeds m^{-1}). Soybean was planted in succession aiming to evaluate the effect of remaining straw on crop performance. Soybean grown in succession to the triple intercropping of corn with marandu and pigeon pea shows increased productivity.

Keywords: *Cajanus cajan* (L.) Millsp.; *Glycine max* L.; *Urochloa brizantha*, integrated crop-livestock system, no-tillage.

INTRODUCTION

Integrated crop livestock systems (ICLS) have gained prominence in agricultural global scenario, in which the synergistic interaction of components provides sustainable intensification in crops and livestock production systems. ICLS contributes for overall efficiency of farms avoiding negatives effects of agricultural production, in which many effects such as soil fertility improvement, greater crop yield, labor efficiency, increase soil biological activity and produce a diversity of foods are listed, enrusing food security around the world (Sekaran *et al.*, 2021).

The versatility of IAPSs allows for several arrangements that are suitable according to the characteristics of the region and production objectives. In the Cerrado, the most attractive modality is autumnal cultivations (off-season), as the intercropped forage generates straw after harvesting grains or plant material for silage for the continuity of the no-tillage system (NTS). NTS is currently an alternative for the sustainability of tropical agricultural systems, promoting protection and improvements in soil physical, chemical, and microbiological quality, contributing to

Submitted on May 10th, 2022 and accepted on September 11th, 2022.
[1] This article is part of the first author master thesis. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.
[2] Universidade Estadual Paulista "Júlio de Mesquita Filho", Faculdade de Engenharia de Ilha Solteira, Departamento de Fitossanidade, Engenharia Rural e Solos, Ilha Solteira, SP, Brazil. roseanaramos15@gmail.com; izabelamgarcia@gmail.com; vivimodesto12@gmail.com; bms.sekiya@unesp.br; deyvison.a.soares@gmail.com; marcelo.andreotti@unesp.br
*Corresponding author: bms.sekiya@unesp.br

increasing crop yield, includind soybean crop (Laroca *et al.*, 2018), as it is the main oilseed cultivated in the world and essential to the Brazilian economy.

Corn stands out among the crops used in ICLS due to its various applications, whether in animal feed, such as grains or silage, or commercialization of dry grains. Intercropping of maize with forage plants presents positive results for both grain yield and silage production (Bessa *et al.*, 2018), such as noticed by Pariz *et al.* (2017) in which the intercropping of maize and marandu grass led to an increase in silage production and the forage itself when compared with monocrops. Corn intercropped with forages in the autumn is an alternative to increasing the amount of straw and nutrient cycling in NTS (Mendonça *et al.*, 2015).

Grasses of the genus *Urochloa* present good performance in integrated systems, as they are an excellent source of forage in animal feed and provide an excellent ground surface cover (Kluthcouski & Yokoyama, 2003; Nascente & Crusciol, 2012) remaining the straw in the area for a long period compared to the straw of other plant species.

Moreover, the intercropping of legume forage species with corn stands out in the increase of silage protein contents, N cycling, and the diversification of soil cover straw for NTS, as the use of species with a high C/N ratio may lead to the temporary immobilization of nitrogen in the soil (Oliveira *et al.*, 2010).

However, in addition to the low availability of cultivars of tropical forage legumes on the market, not all of them have the potential for use in intercropping due to the competition effect. Pigeonpea (*Cajanus cajan* L. Millsp.) stands out among the forages used in the Cerrado region due to its high potential for forage production for cutting or protein bank. This species improves the physicochemical conditions of soils and has the potential for intercropping with annual crops due to its erect growth habit and type of taproot system. Furthermore, this legume has good adaptation in clayey soils and can be used in intercropping with grasses, as it fixes atmospheric N_2 (Balbino *et al.*, 2011).

The ensilage practice using crops that produce grains intercropped with tropical forage species, both grasses and legumes, have functions that go beyond animal feeding, as they also contribute to improving the production environment. Regrowth process of forage plants provides straw for NTS so that the plant residues present on the soil surface benefit crops sown in succession, increasing grain yield, and providing improvements in soil physical, chemical, and biological properties (Garcia *et al.*, 2004).

Thus, this research aimed to evaluate the effect of the straw from the regrowth of five sowing densities of pigeonpea intercropped with corn and/or marandu grass harvested for silage in the second crop season on the development and yield of soybean in succession.

MATERIAL AND METHODS

The experiment was carried out in the municipality of Selvíria, Mato Grosso do Sul State, Brazil (20°20′05″ S and 51°24′26″ W, altitude of 335 m) from November 2016 to March 2017 and November 2017 to February 2018. The soil in the area was classified as a clayey-textured typic dystrophic Red Latosol (Oxisol) (Santos *et al.*, 2018). The climate is classified as humid tropical, Aw according to the Köppen classification, with a rainy season in the summer and a dry season in the winter. The climate data of the experimental period, referring to the maximum, mean, and minimum temperature and rainfall were collected at the meteorological station located at the Teaching, Research, and Extension Farm (FEPE) of Unesp in Selvíria, MS, Brazil.

The experiment was carried out under low altitude Cerrado conditions, in an experimental area cultivated under NTS for six years, with corn being the predecessor crop intercropped with marandu grass and/or pigeonpea (March 2016) intended for silage production.

Soil analysis at a depth of 0.0 to 0.20 m, carried out according to the methodology of Raij *et al.* (2001) before the experiment was set up, showed the following chemical attributes in 2016/17: P (resin) = 35 mg dm^{-3}; organic matter (OM) = 27 g dm^{-3}; pH ($CaCl_2$) = 5.5; K^+ = 2.9; Ca^{2+} = 37; Mg^{2+} = 29; H+Al = 29; Al^{3+} = 0; sum of bases (SB) = 68.9; cation exchange capacity (CEC) = 98.3 $mmol_c$ dm^{-3}; and base saturation (V) = 69%. In 2017/2018 the chemical atributes were: P (resin) = 20 mg dm^{-3}; organic matter (OM) = 29 g dm^{-3}; pH ($CaCl_2$) = 5.0; K^+ = 10.6; Ca^{2+} = 32, Mg^{2+} = 24; H+Al = 38; Al^{3+} = 0, sum of bases (SB) = 66.6; cation exchange capacity (CEC) = 104.6 $mmol_c$ dm^{-3}; and base saturation (V) = 64%.

The experimental design was randomized blocks in a 2×5 factorial arrangement, with four replications. The treatmens consisted in two types of intercropping (1. Corn+ Marandu + Pigeonpea; 2. Corn + Pigeonpea) at five sowing densities of inter-row pigeonpea, as follows: a) off-season corn intercropped with five sowing densities of pigeonpea (0, 6, 12, 18, and 24 seeds m^{-1}) and b) off-season corn intercropped with marandu grass and five sowing densities of pigeonpea (0, 6, 12, 18, and 24 seeds m^{-1}).

The experiment consisted of 40 plots of 20 m in length and 3.6 m in width, and the useful evaluation area consisted of three central rows of 18 m in length of each plot set up in the same areas in both seasons.

Corn was sown in May 2016 and May 2017 intercropped or not with marandu grass (60% PLS with 7 kg ha^{-1} of seeds) in the row under NTS at a depth of 0.06 m, using a seed-cum-fertilizer drill provided with a third box where the grass seeds were conditioned and a rod-type furrow opener mechanism (machete). The corn hybrid was DKB 350 YR, sown at a density of 3.3 seeds per meter, spaced at 0.45 m between rows, targeting a population of around 66,000 plants ha^{-1}.

Pigeonpea 'Aratá' was sown in the inter-row of corn, also at a spacing of 0.45 m, at densities of 0, 6, 12, 18, and 24 seeds m^{-1}, using the same seed drill used for corn and on the same day of corn sowing with or without grass.

Corn intercropping was harvested in September 2016 and September 2017 aiming at silage production, with a cutting height of 0.30 m. The average productivity of dry matter for silage was 38,7 t ha^{-1} in 2016 and 33,5 t ha^{-1} in 2017. After ensiling, the post-harvest residue remained under rest for grass and pigeonpea regrowth. The area was desiccated after regrowth (around 60 days) to form straw, using the herbicides glyphosate (1560 g ai ha^{-1}) and Select (1.0 L ha^{-1}), with subsequent reap of plant residues using a horizontal shredder (Triton). Average regrowth residue was 5,0 t ha^{-1} for corn with pigeonpea intercropping, and 8,5 t ha^{-1} for intercropping of corn with Marandu and pigeonpea.

Then, soybean was sown using the cultivar BMX Potência RR on November 15, 2016, and November 10, 2017, at a density of approximately 16 seeds per meter of furrow, with an inter-row spacing of 0.45 m, aiming at a stand of 300,000 plants ha^{-1}, using a seed-cum-fertilizer drill a rod-type furrow opener (machete) for NTS.

Soybean seeds were treated with Vitavax-Thiram and inoculated with bacteria of the genus *Bradyrhizobium japonicum* (600,000 cells/gram of seeds), and the base fertilization consisted of 370 kg ha^{-1} of the NPK formulation 04-20-20 (14.8 kg N ha^{-1}, 74.0 kg P_2O_5 ha^{-1}, and 74.0 kg K_2O ha^{-1}) in the first growing season and 350 kg ha^{-1} of the NPK formulation 04-30-10 (14.0 kg N ha^{-1}, 105.0 kg P_2O_5 ha^{-1}, and 35.0 kg K_2O ha^{-1}) in the second growing season, as recommended by Boletim Técnico 100 (Raij *et al.*, 1997). No further fertilization was carried out. Phytosanitary management was carried out according to the crop requirements. Soybean was harvested in late February 2017 and early March 2018.

The evaluations of morphological components and production were carried out by collecting 10 soybean plants in the useful area to obtain the plant height, first-pod height, the number of pods per plant, and the number of grains per pod.

All plants from 6 m of each experimental unit (two 3-m rows) were counted, manually harvested, and threshed on a mechanical threshing machine to determine the final stand and grain yield. Subsequently, the moisture was corrected to 13% (wet basis) and grain yield was calculated. A sample of grains was taken to the laboratory to determine the 100-grain weight. The grains were counted on an electronic counter and weighed on a precision electronic balance, with means of four samples.

The results were subjected to the Shapiro-Wilk normality test and the analysis of variance using the F-test ($P \leq 0.05$). The effect of residues with or without grass was compared by Tukey's test ($P \leq 0.05$). The effect of pigeonpea sowing density, when significant, was evaluated by regression analysis ($P \leq 0.05$). The analysis was performed using the SISVAR® software (Ferreira, 2008).

RESULTS AND DISCUSSION

The 2016/17 agricultural year presented a higher plant final stand (PFS) of soybean on the residue from the intercropping with marandu grass (Table 1). Krutzmann *et al.* (2013) found similar results in the intercropping of *U. brizantha* with Tanzania grass, predecessors to the soybean crop. However, different results from those observed in the present study are reported in the literature (Nascente & Crusciol, 2012; Chioderoli *et al.*, 2012), which are attributed to abiotic factors, mainly the climate and soil of each region.

In this context, less water retention may have occurred on the soil surface at germination due to the absence of straw on the soil of the plot without grass and the rapid pigeonpea straw decomposition, which may have influenced the initial growth of soybean seedlings (Figure 1). Soybean PFS was not influenced by pigeonpea sowing density or the interaction between density and intercropping with marandu grass (Table 1).

Table 1: Plant final stand (PFS) and plant height (PH) of soybean grown on the residual straw of corn intercropped with pigeonpea at five sowing densities with or without *Urochloa brizantha* 'Marandu' in the 2016/17 and 2017/18 agricultural years

Treatment	**PFS (plants ha^{-1})**	**PFS (plants ha^{-1})**	**PH (cm)**	**PH (cm)**
	2016/17	2017/18	2016/17	2017/18
Sowing				
Corn + pigeonpea + marandu grass	258,055 a	250,617	103	131
Corn + pigeonpea	230,277 b	259,408	104	130
Density (seeds m^{-1})				
0	215,278	245,986	106	136
6	243,055	237,037	102	129
12	240,972	263,580	101	132
18	278,472	277,314	106	127
24	243,055	251,143	103	129
P > F				
Sowing	0.047	0.180	0.708	0.693
Density	0.080	0.114	0.050	0.124
Sowing x Density	0.920	0.148	0.132	0.123
CV (%)	**17.3**	**8.0**	**3.6**	**5.8**

Means followed by different letters in the column differ from each other by Tukey's test at a 5% probability. CV: coefficient of variation.

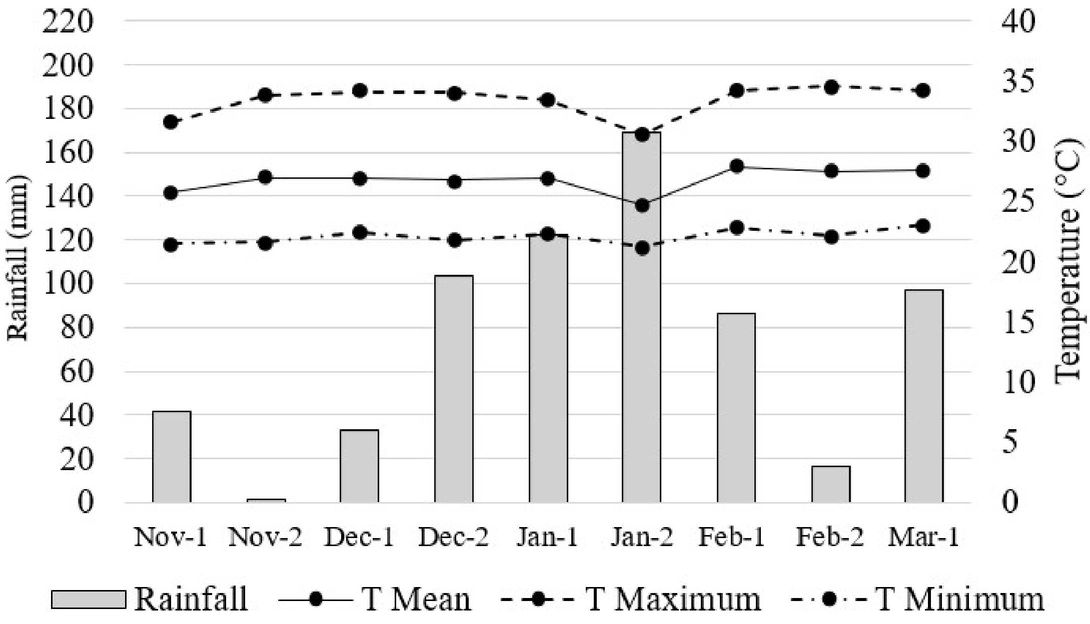

Figure 1: Maximum, mean, and minimum temperatures and rainfall presented in fortnights, during the experimental period in the 2016/17 agricultural year.

The following agricultural year (2017/18) showed no effect of intercropping with grass, as well as pigeonpea sowing densities, and the interaction between intercropping with grass and pigeonpea sowing densities on soybean PFS. It is due to the higher rainfall distribution in the second growing season (Figure 2), with higher rainfall in the initial development, providing a homogeneous stand in the treatments. Thus, it is clear the importance of the effect of *Urochloa* straw in soil cover, demonstrating that marandu grass straw under restrictive climate conditions, such as lack or irregularity of rains and critical periods (e.g., plant establishment stage), has a pronounced effect on plant developmet associated with variations in rainfall throughout the year.

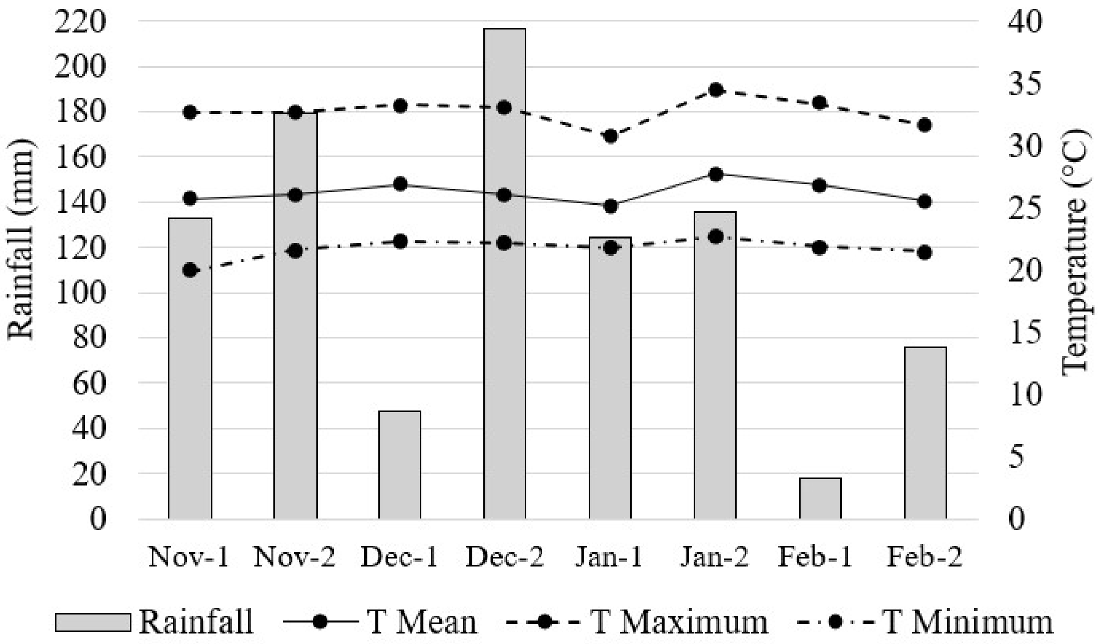

Figure 2: Maximum, mean, and minimum temperatures and rainfall, presented in fortnights, during the experimental period in the 2017/18 agricultural year.

Plant height (PH) presented no difference as a function of the isolated effect of intercropping with grass, sowing density of the predecessor pigeonpea, and the interaction between them in both agricultural years (Table 1). Plant height is influenced by the length of the vegetative period, in which the range from 0.80 to 0.96 m is the minimum height considered normal for the crop (Pereira Júnior *et al.*, 2010), as these values reduce the losses of pods not harvested in mechanized harvesting (Chioderoli *et al.*, 2012). Therefore, the mean value observed in the present study is above the minimum required.

Intercropping with marandu grass provided higher first-pod height (FPH) (Table 2) in the 2016/17 growing season although the plants showed the same PH, which may be related to the straw effect, which provides higher soil moisture and supply of N, P, and Ca with residual grass. Garcia *et al.* (2014) observed no differences when evaluating the effect of straw decomposition in the corn/*Urochloa* and corn/*Megathyrsus maximus* intercropping and residual nitrogen fertilization for soybean FPH in an area close to that of the present study.

The 2017/18 agricultural year showed no difference for FPH according to the inclusion or not of grass, as observed for PH, due to favorable climate conditions, which provided uniform cultivation. No difference was observed for FPH as a function of the isolated effect of the sowing density of the predecessor pigeonpea. Also, no interaction was observed between factors for this soybean morphological attribute (Table 2) in both agricultural years.

The number of pods per plant (NPP) was higher for soybean cultivation on plant residues without intercropping with marandu grass (Table 2) in the 2016/17 growing season. Table 1 shows that the lowest plant stand was found in this treatment, which indicates that the highest NPP for this treatment can be attributed to the compensation capacity that soybean plants have when there is a reduction in plant density, increasing the individual legume production, mainly in cultivars with an indeterminate growth habit. According to Procópio *et al.* (2013), soybean has a high ability to compensate for lower plant densities, mainly forming a higher number of legumes per individual when the population is reduced. Krutzmann *et al.* (2013) also found similar NPP values for soybean grown on *U. brizantha* ‘Marandu’ straw.

Table 2: First-pod height (FPH) and number of pods per plant (NPP) of soybean grown on the residual straw of corn intercropped with pigeonpea at five sowing densities with or without *Urochloa brizantha* ‘Marandu’ in the 2016/17 and 2017/18 agricultural years

Treatment	FPH (cm)	FPH (cm)	NPP (pod plant^{-1})	NPP (pod plant^{-1})
	2016/17	2017/18	2016/17	2017/18
Sowing				
Corn + pigeonpea + marandu grass	16 a	23.7	45 b	37.2
Corn + pigeonpea	14 b	21.6	54 a	35.3
Density (seeds m^{-1})				
0	15	23.6	50	34.5
6	15	25.0	53	36.6
12	15	22.1	51	34.0
18	16	20.0	45	38.0
24	16	23.0	50	38.2
P > F				
Sowing	0.003	0.194	0.006	0.374
Density	0.297	0.381	0.511	0.639
Sowing x density	0.168	0.638	0.092	0.288
CV (%)	**10.6**	**22.0**	**19.4**	**18.7**

Means followed by different letters in the column differ from each other by Tukey’s test at a 5% probability. CV: coefficient of variation.

The 2017/18 agricultural year showed no difference between treatments for NPP, which is related to the higher crop uniformity due to a better rainfall distribution (Figure 2).

As observed for NPP, the number of grains per pod (NGP) was higher in soybean cultivation without marandu grass residues (Table 3) in the first growing season (2016/17) due to the compensation ability of soybean plants, resulting in higher numbers of grains derived from the higher number of pods in smaller stands. However, the water input was not sufficiently adequate and distributed to promote grain filling, necessary to evidence this effect, result in larger grains, and have an effect on the 100-grain weight (100W), which was similar between treatments. No significant effect was observed for pigeonpea sowing densities nor for the interaction between intercropping with grass and pigeonpea sowing density for NGP (Table 3).

NPP and 100W showed no significant differences in intercropping with grass and pigeonpea at different densities in the 2017/18 agricultural year due to the effect of plant population homogeneity and better rainfall distribution (Figure 2).

Grain yield in the 2016/17 growing season showed no significant difference for the isolated effect of intercropping with marandu grass, pigeonpea sowing density, and the interaction between intercropping with marandu grass and pigeonpea sowing density (Table 4). The regression analysis presented no adjustment for grain yield (R^2 = 0,3447), what could be associated with a large variation in the first year, mainly due to water stress in the early stages of plant development, which contributed to negative effects on plots formation.

Table 3: Number of grains per pod (NGP) and 100-grain weight (100W) of soybean grown on the residual straw of corn intercropped with pigeonpea at five sowing densities with or without *Urochloa brizantha* 'Marandu' in the 2016/17 and 2017/18 agricultural years

Treatment	**NGP (grains pod⁻¹)**	**NGP (grains pod⁻¹)**	**100W (g)**	**100W (g)**
	2016/17	2017/18	2016/17	2017/18
Sowing				
Corn + pigeonpea + marandu grass	2.1 b	2.1	12.9	14.4
Corn + pigeonpea	2.2 a	2.0	12.9	13.5
Density (seeds m⁻¹)				
0	2.1	2.1	13.3	13.5
6	2.3	1.9	12.9	15.1
12	2.2	2.2	12.7	12.8
18	2.0	2.1	12.9	13.9
24	2.2	2.1	12.7	14.2
P > F				
Sowing	0.021	0.117	0.427	0.100
Density	0.355	0.416	0.973	0.111
Sowing x density	0.156	0.658	0.552	0.476
CV (%)	**23.2**	**13.7**	**5.6**	**11.8**

Means followed by different letters in the column differ from each other by Tukey's test at a 5% probability. CV: coefficient of variation.

The presence of grass in the predecessor cultivation did not affect grain yield, as observed by Krutzmann *et al.* (2013) for soybean planted on different vegetation cover, which showed that the vegetation cover from *U. ruziziensis* and *U. brizantha* 'Marandu' pastures intercropped with Tanzania grass did not influence soybean yield. Pacheco *et al.* (2011) also observed that soybean yield was not influenced when grown on residues of *Urochloa ruziziensis*, *Urochloa brizantha* 'Marandu', millet (*Pennisetum glaucum*), intercropping *Urochloa ruziziensis* + pigeonpea, and fallow.

On the other hand, Chioderoli *et al.* (2012) observed that the production of soybean grown on residues of *Urochloa brizantha* 'Marandu' reached values above the regional mean in high technology areas, with an overall mean of 4.1 Mg ha^{-1}, but in an area irrigated by of center pivot.

The presence of grass in the predecessor intercropping in the 2016/17 agricultural year did not change soybean yield due to the compensatory effect between the other components of production because, even with a higher number of pods per plant and grains per pod in the treatment without grass, the highest stand occurred in its presence. Moreover, the 100-grain weight showed no effect, equaling the yield between treatments.

The following agricultural year (2017/18) presented differences in soybean grain yield, which was higher in the successor cultivation to the intercropping with marandu grass (Table 4). Although not significant, NPP (Table 2), NGP, and 100W (Table 3), associated with the compensatory effect of the lower PFS (Table 1), were numerically higher in soybean cultivation with marandu grass residues when compared to cultivation without grass (Table 2). It may have led to the interaction between these variables, reflecting a higher grain yield in the 2017/2018 growing season. The regression analysis presented increasing linear adjustment ($R^2 = 0,8142$), according to inclusion level of pigeonpea.

Table 4: Yield of soybean grown on the residual straw of corn intercropped with pigeonpea at five sowing densities with or without *Urochloa brizantha* 'Marandu' in the 2016/17 and 2017/18 agricultural years

Treatment	Yield (kg ha^{-1})	Yield (kg ha^{-1})
	2016/17	2017/18
Sowing		
Corn + pigeonpea + marandu grass	2504	3616 a
Corn + pigeonpea	2672	3114 b
Density (seeds m^{-1})		
0	2685	3015
6	2902	3213
12	2273	3188
18	2457	3744
24	2844	3661
P > F		
Sowing	0.790	0.008
Density	0.012	0.052
Sowing x density	0.879	0.303
CV (%)	**17.9**	**16.4**

Means followed by different letters in the column differ from each other by Tukey's test at a 5% probability. CV: coefficient of variation. [(1)] $Y = 82,357x^2 - 506,84x + 3246,8$ ($R^2 = 0,3447$); [(2)] $y = 182,3x + 2817,3$ ($R^2 = 0,8142$).

Pariz *et al.* (2020) analyzed a triple intercropping of corn + pigeonpea + marandu grass for silage associated with black oat in overseeding for sheep grazing during three seasons and observed that this type of intercropping was a highly effective option for silage production and the improvement of other system yield elements, with higher straw coverage and soybean yield in succession in the fourth growing season.

The interaction of the isolated effects of crops shows positive results despite the higher interspecific competition between crops and the higher complexity of the system in these triple intercrops. The soil exploration by the root system in the intercropping of corn with *Urochloa*, together with the produced straw, favors water infiltration, the reduction in the erosive process, and the use of water and nutrients, contributing to higher values of soybean grain yield and maintaining system stability (Chioderoli *et al.*, 2012). Likewise, the intercropping between corn and pigeonpea is promising in promoting improvements in soil structure (Chieza *et al.*, 2013), in addition to presenting the ability to biologically fix nitrogen and make it available for the successor crop, as it is a legume.

Added to the effects on soil physicochemical attributes, this intercropping is very beneficial, reflecting in positive responses of the crop in succession. According to Pariz *et al.* (2020), this type of intercropped cultivation presents better cycling and nutrient use efficiency. Thus, the triple intercropping with corn, pigeonpea, and marandu grass is a productive and highly sustainable system.

CONCLUSIONS

Soybean grown in succession to the triple intercropping of corn with marandu and pigeon pea shows increased productivity.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

There are no conflicts of interest in carrying out the research and publishing the manuscript.

REFERENCES

Balbino LC, Cordeiro LAM, Silva VPD, Moraes A, Martínez GB, Alvarenga RC, Kichel NA, Fontaneli RS, Santos HP, Franchini JC & Galeran PR (2011) Evolução tecnológica e arranjos produtivos de sistemas de integração lavoura-pecuária-floresta no Brasil. Pesquisa Agropecuária Brasileira, 46:110-114.

Bessa SV, Backes C, Santos AJM, Rodrigues LM, Teodoro AG, Tomazello DA, Rezende PR, Ribon AA, Leite LLF & Giongo PR (2018) Maize silage intercropped with grass and pigeon pea subjected to different N rates and pasture development in the offseason. Semina: Ciências Agrárias, 39:2501-2516.

Chieza ED, Lovato T, Araújo ES & Tonin J (2013) Propriedades físicas do solo em área sob milho em monocultivo ou consorciado com leguminosas de verão. Revista Brasileira de Ciência do Solo, 37:1393-1401.

Chioderoli CA, Mello LMM, Grigolli PJ, Furlani CEA, Silva JOR & Cesarin AL (2012) Atributos físicos do solo e produtividade de soja em sistema de consórcio milho e braquiária. Revista Brasileira de Engenharia Agrícola e Ambiental, 16:37-43.

Ferreira DF (2008) Sisvar: um programa para análises e ensino de estatística. Revista Científica Symposium, 6:36-41.

Garcia CMDP, Andreotti M, Teixeira Filho MCM, Lopes KSM & Buzetti S (2014) Decomposição da palhada de forrageiras em função da adubação nitrogenada após o consórcio com milho e produtividade da soja em sucessão. Bragantia, 73:143-152.

Garcia R, Rocha FC, Bernardino FS & Gobbi KF (2004) Forrageiras utilizadas no sistema integrado agricultura-pecuária. In: Zambolim L, Silva AA da & Agnes EL (Eds.) Manejo integrado: integração agricultura-pecuária. Viçosa, UFV. pp.331-352.

Kluthcouski J & Yokoyama LP (2003) Opções de integração lavoura-pecuária. In: Kluthcouski J, Stone LF & Aidar H (Eds.) Integração lavoura-pecuária. Santo Antônio de Goiás, Embrapa Arroz e Feijão. pp.131-141.

Laroca JCS, Souza JMA, Pires GC, Pires GJC, Pacheco LP, Silva FD, Wruck FJ, Carneiro MAC, Silva LS & Souza ED (2018) Soil quality and soybean productivity in crop-livestock integrated system in no-tillage. Pesquisa Agropecuária Brasileira, 53:1248-1258.

Raij B Van, Andrade JC, Cantarella H & Quaggio JA (2001) Análise química para avaliação da fertilidade de solos tropicais. Campinas, Instituto Agronômico. 284p.

Raij B Van, Silva NM, Cantarella H, Quaggio JA & Furlani AMC (1997) Recomendações de adubação e calagem para o Estado de São Paulo. 2ª ed. Campinas, Instituto Agronômico. 285p.

Mendonça VZ, Mello LMM, Andreotti M, Pariz CM, Yano ÉH & Pereira FCB (2015) Liberação de nutrientes da palhada de forrageiras consorciadas com milho e sucessão com soja. Revista Brasileira de Ciência do Solo, 39:183-193.

Nascente AS & Crusciol CAC (2012) Cover crops and herbicide timing management on soybean yield under no-tillage system. Pesquisa Agropecuária Brasileira, 47:187-192.

Oliveira LB, Pires AJV, Viana AES, Matsumoto SN, Carvalho GGP & Ribeiro LSO (2010) Produtividade, composição química e características agronômicas de diferentes forrageiras. Revista Brasileira de Zootecnia, 39:2604-2610.

Pacheco LP, Leandro WM, Machado PLO, Assis RL, Cobucci T, Madari BE & Petter FA (2011) Produção de fitomassa e acúmulo e liberação de nutrientes por plantas de cobertura na safrinha. Pesquisa Agropecuária Brasileira, 46:17-25.

Pariz CM, Costa C, Crusciol CAC, Meirelles PRL, Castilhos AM de, Andreotti M, Costa NR & Martello JM (2017) Silage production of maize intercropped with tropical forages in an integrated crop-livestock system with lambs. Pesquisa Agropecuária Brasileira, 52:54-62.

Pariz CM, Costa NR, Costa C, Crusciol CAC, Castilhos AM, Meirelles PRL, Calonego JC, Andreotti M, Souza DM, Cruz IV, Longhini VZ, Protes VM, Sarto JRW, Piza MLST, Melo VFP, Sereia RC, Fachiolli DF, Almeida FA, Souza LGM & Franzluebbers AJ (2020) An innovative corn to silage-grass-legume intercropping system with oversown black oat and soybean to silage in succession for the improvement of nutrient cycling. Frontiers in Sustainable Food Systems, 4:01-20.

Pereira Júnior P, Rezende PM, Malfitano SC, Lima RK, Corrêa LVT & Carvalho ER (2010) Efeito de doses de silício sobre a produtividade e características agronômicas da soja [*Glycine max* (L.) Merrill]. Ciência & Agrotecnologia, 34:908-913.

Procópio SO, Balbinot Junior AA, Debiasi H, Franchini JC & Panison F (2013) Plantio cruzado na cultura da soja utilizando uma cultivar de hábito de crescimento indeterminado. Revista de Ciências Agrárias: Amazonian Journal of Agricultural and Environmental Sciences, 56:319-325.

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JÁ, Araujo Filho JC, Oliveira JB & Cunha TJF (2018) Sistema brasileiro de classificação de solos. 5ª ed. Brasília, Embrapa. 590p.

Sekaran U, Lai L, Ussiri DAN, Kumar S & Clay S (2021) Role of integrated crop-livestock systems in improving agriculture production and addressing food security – A review. Journal of Agriculture and Food Research, 5:100190.

Krutzmann A, Cecato U, Silva PA, Tormena CA, Iwamoto BS & Martins EM (2013) Palhadas de gramíneas tropicais e rendimento da soja no sistema de integração lavoura pecuária. Bioscience Journal, 29:842-851.