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Corn yield for ensilage in consortium with green manure and bean in succession

Produtividade de milho para ensilagem em consórcio com adubos verdes e de feijão em sucessão

Productividad del maíz para ensilaje en cultivo intercalado con abonos verdes y judías en sucesión

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Abstract
This paper aimed to evaluate the productivity of corn crop for silage, beans and straw production in different crop rotation systems with spring/summer and fall/winter green manures cultivated under agroecological production management. The experiment was implemented in a rural property managed in an agroecological system since 2009, in the 2017/18 and 2018 crops. The experimental design used was in randomized blocks, with five repetitions. The treatments consisted of four different crop rotation systems: monocrop corn/monocrop corn/fallow/beans; corn + cowpea/monocrop corn/oats/beans; corn + crotalaria/monocrop corn/forage radish/beans and corn + jack bean/monocrop corn/vetch/beans. After the 2018 second crop of corn was removed, the winter/spring green manures were sown: forage radish, vetch, and oats. This was followed in September by the bean crop. The dry matter yields of corn for silage in each growing season and of the bean were evaluated, as well as the total productivity of the systems. The straw yield was also evaluated. The crop rotation systems that included green manures presented the highest total productivity. The intercropping with pork bean favored the corn productivity in the harvest and the crotalaria stover favored the productivity in the off-season. The corn + cowpea/jack bean/beans monocrop and corn + crotalaria/jack bean/forage radish/beans systems favored the productivity of beans. The mode corn monocrop/corn monocrop/fallow did not prioritize the accumulation of straw on the soil.
Keywords: Consortium; Green manure; Ensilage; Organic production.

Resumo
Este trabalho teve por objetivo avaliar a produtividade da cultura de milho para ensilagem, feijão e a produção de palhada em diferentes sistemas de rotação de culturas com adubos verdes de primavera/verão e outono/inverno, cultivados sob manejo agroecológico de produção. O experimento foi implantado em uma propriedade rural manejada em sistema agroecológico desde 2009, nas safras de 2017/18 e 2018. O delineamento experimental utilizado foi em blocos casualizados, com 5 repetições. Os tratamentos foram constituídos por quatro diferentes sistemas de rotação de culturas: milho monocultivo/milho monocultivo/pousio/ feijão; milho + feijão-guandu/ milho monocultivo/ aveia/ feijão; milho + crotalária/ milho monocultivo/nabo forrageiro/feijão e milho + feijão-de-porco/milho monocultivo /ervilhaca/ feijão. Após a retirada do milho safrinha de 2018 foram semeados os adubos verdes de inverno/primavera: nabo forrageiro, ervilhaca e aveia. Em seguida no mês de setembro a cultura do feijoeiro. Foram avaliadas as produtividades de matéria seca de milho para ensilagem em cada estação de cultivo e do feijão; bem como, a produtividade total dos sistemas. Avaliou-se também a produtividade de palhada. Os sistemas de rotação de culturas que incluíram os adubos verdes apresentaram a maior produtividade total. O consórcio com feijão-de-porco favoreceu a produtividade de milho na safra e a palhada da crotalária a produtividade na safrinha. Os sistemas de milho + feijão-guandu/milho monocultivo/aveia/feijão e milho + crotalária/milho monocultivo/nabo forrageiro/feijão favoreceram a

produtividade do feijão. A modalidade milho monocultivo/milho monocultivo/pousio não priorizou a acúmulo de palhada sobre o solo.
Palavras-chave: Consórcio; Adubos verdes; Ensilagem; Produção orgânica.

Resumen

Este trabajo tuvo como objetivo evaluar la productividad del cultivo de maíz para ensilaje, frijol y producción de paja en diferentes sistemas de rotación de cultivos con abonos verdes de primavera/verano y otoño/invierno, cultivados bajo un manejo de producción agroecológico. El experimento se implementó en un predio rural manejado en sistema agroecológico desde 2009, en las cosechas de 2017/18 y 2018. El diseño experimental utilizado fue en bloques aleatorios, con 5 repeticiones. Los tratamientos consistieron en cuatro sistemas diferentes de rotación de cultivos: maíz monocultivo/maíz monocultivo/fríjol; maíz + caupí/maíz monocultivo/avena/frijol; maíz + crotalaria/maíz monocultivo/nabo forrajero/frijol y maíz + frijol porcino/maíz monocultivo/ervillaca/frijol. Después de la retirada del maíz de retoño de 2018 se sembraron los abonos verdes de invierno/primavera: nabo forrajero, veza y avena. En septiembre le siguió la cosecha de judías. Se evaluaron los rendimientos de materia seca del maíz para ensilaje en cada temporada y de la judía; así como, la productividad total de los sistemas. También se evaluó la productividad de los rastrojos. Los sistemas de rotación de cultivos que incluían abonos verdes presentaron la mayor productividad total. El intercalado con caupí favoreció la productividad del maíz en la cosecha y la de los rastrojos de crotalaria en la contraestación. Los sistemas maíz + caupí/monocultivo de maíz/avena/frijoles y maíz + crotalaria/monocultivo de maíz/nabo forrajero/frijoles favorecieron la productividad de los frijoles. La modalidad monocultivo de maíz/monocultivo de maíz/pousseed no priorizó la acumulación de paja en el suelo.
Palabras clave: Cultivo intercalado; Abonos verdes; Ensilaje; Producción ecológica.

1. Introduction

Agricultural production systems must be managed to promote the improvement or adequate maintenance of the parameters that ensure the support of plant growth. Management mistakes practiced in conventional grain cultivation systems have led this system to unsustainability with direct negative impacts to the rural producer and the environment. An alternative to this problem is to use the precepts of agroecology to favor the agroecosystem's sustainability, considering the economic, social, cultural and environmental factors in food production (Padovan et al., 2016).

According to Lizarelli (2016), the term agroecological agriculture can be used to denote the different productive proposals; whose philosophical current meets the production requirements with a focus on imitation of natural processes. In agroecology, agricultural management is carried out according to the local characteristics of the environment, changing them as little as possible (Primavesi, 2008).

Modifying monocrop-based cropping systems to agroecological-based systems is a dynamic process peculiar to each farm, not only requiring the substitution of synthetic inputs for natural ones, such as replacing synthetic fertilizers with green manure, but also maintaining soil coverage, using plants adapted to the climate and management conditions, allied to a set of practices to redesign the landscape of the farm (Padovan & Campolin, 2011).

In the Western region of Paraná, more than 80% of the areas of rural properties are occupied by the cropping of annual grains. This production is destined for commercialization or silage production (Paraná, 2016; Souza et al., 2018). Silage production is a common practice in the region, which presents a period of climatic seasonality during the fall/winter that compromises the production and availability of fresh fodder, limiting the volume and quality of bulks for feeding the herds. To keep them productive this season, fodder preserved in silage form is included as one of the food sources in the diet. Corn is one of the most used forage plants in silage because it has high dry mass productivity per hectare, well-established cultivation technology and good nutritional value for animals (Moreira et al., 2014).

Some farmers dedicate their areas to successive crops of corn for silage. However, this crop can export up to 16 t ha^{-1} of dry matter, leaving little straw for soil coverage and forming organic matter in crop areas. This results in nutrient imbalance decreased productivity, and silage quality in subsequent crops, besides the acceleration of soil degradation processes (A. M. Coelho, 2006; Santos et al., 2009).

The absence of straw, combined with the transit of agricultural machinery under inadequate soil moisture conditions (plastic soil), favors the formation of compacted layers (MORAES et al., 2016). From the point of view of soil physics, compaction directly and negatively influences crop yields, reduces macropores, and increases soil resistance to root penetration, reducing the volume and supply of water and nutrients to plants (Pellegrini et al., 2016).

Adopting cover crops and green manure for the soil after corn is harvested for silage is not a common practice in the management of agricultural areas (Vieira et al., 2011). The soil remains bare until the following harvest. Soil fallow during this period contributes to the degradation of the physical, chemical, and biological properties of the soil and to a more significant infestation of weeds that, besides not producing an adequate volume of straw, favor the weed seed bank and increase production costs (Kluthcouski et al., 2004; Martin et al., 2011).

In the properties of western Paraná, it is not common to cultivate cover crops and green manure, which avoid fallow between harvests, even among producers who use agroecological precepts of production. In the fall/winter season, oats or corn (safrinha) are grown. When silage is produced with second crop corn, succession with soybeans or beans predominates (Mottin et al., 2018; Souza et al., 2018).

Several plant species, such as Crotalaria spectabilis, cowpea, jack bean, vetch, and forage radish, can be used as cover and green manure in crop rotation planning. However, they are little disseminated and used by farmers to compose the production system and avoid problems arising from the low deposition of plant residues in the soil by cultivation for silage (Moreira et al., 2014; Vieira et al., 2011).

These plants can be grown as intercrops or in succession to the crop of interest, and their function is to increase the dry matter added to the soil, promote soil quality and increase the productivity of the main crop (Dan et al., 2012). The main characteristics of these crops are the fast establishment, high dry matter production, ease of management, deep root system, efficiency in nutrient cycling, and not promoting infestation by diseases and pests (Marcelo et al., 2012).

One of the most significant difficulties in adopting green manures to compose the cropping system is the fact that each one has its peculiarities, and based on the literature, there is no conclusion on the interference of these plants in the productivity of corn crop for silage and the residues deposited on the soil. Many studies found that intercropping corn with green manures negatively affected the crop's productivity and the deposition of residues on the soil (Almeida Junior, 2015; Jakelaitis et al., 2010; Pariz et al., 2011).

While there are other studies where intercropping positively influenced productivity (Batista et al., 2011; Chioderoli, Mello, et al., 2012; Martinez et al., 2019; Paz et al., 2017; Seidel et al., 2014), the same precepts hold for research where corn is grown in succession to green manure plants. According to Marcelo, et al., (2012) and Brito et al. (2017), there are increases in corn productivity and residues in the soil in succession cultivation. At the same time, Carvalho et al. (2015) and Carvalho et al. (2011) found contrary results on productivity.

The results are also controversial for the productivity of beans; some studies indicate that planting under Fabaceous straw produces inexpressive amounts of dry matter in the soil and does not influence the productivity of the bean (Almeida Junior, 2015; Correia et al., 2012). Some, however, point to increases in bean productivity when cultivated under Poaceae and Fabaceae (Mottin et al., 2018; Seidel et al., 2012; Torres et al., 2014).

It is clear from these observations that there is no ideal plant to compose the rotation between crops. Before choosing one, it is necessary to survey the most favorable species for the cropping system. Information should be sought about their adaptation to the region's climate, sowing season, crop cycle, root system development, and dry mass production (Negrini, 2007). Thus, it is necessary to choose plant species that overcome the restrictions and promote the recovery of soil quality, especially when subjected to an intensive production system ensuring increases in the system's productivity.

In this context, this study's objective was to evaluate corn's productivity for silage, beans in succession and straw production in different crop rotation systems with spring/summer and fall/winter green manures grown under agroecological production management.

2. Methodology

Location, climate, and soil of the study site

The experiment was conducted on a farm in the municipality of Missal - PR, managed under an agroecological system since 2009. According to the Köppen classification, the climate of the region is mesothermal humid subtropical (Cfa), with hot summers, average temperatures above 22ºC and winters below 18ºC, and an average annual rainfall of 1600 - 1800 mm (IAPAR - INSTITUTO AGRONÔMICO DO PARANÁ, 2010).

The soil of the experimental unit was classified according to SANTOS et al. (2013) as Oxisol, with a clayey texture.

The experimental area had been cultivated for two years with cassava; before the implementation of the experiment, the previous crop was removed, and a light harrow was made for incorporation and elimination of the initial population of spontaneous plants and to uniform the soil surface. Then soil samples were collected from 0 to 0.20 m depth to determine the chemical characteristics. The chemical analyses were performed according to the methodology of Raij et al. (2001) in the Environmental and Instrumental Chemical Analysis laboratories of UNIOESTE. The results obtained are presented in Table 1.

Table 1 - Soil chemical analysis (0 to 20 cm depth) collected from the experimental area.

pH	**O.M**	**P**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**Al^{3+}**	**H^{+}+ Al^{3+}**	**V**
($CaCl_2$)	(g dm^{-3})	(mg dm^{-3})	----------------$cmol_c$ dm^{-3} -----------					(%)
4,97	17,77	11,64	13,35	2,35	0,38	0,31	4,77	77,12

Source: Author's elaboration.

The climatological data for the experiment period were obtained from the Medianeira - PR Meteorological Station, installed at the UTFPR in agreement with IAPAR and located at 25° 10' South latitude and 54° 07' West longitude, 466 m above sea level. The average monthly values for precipitation and temperature (minimum, middle, and maximum) and climatological data for the period during which the experiment was conducted are shown in Figure 1.

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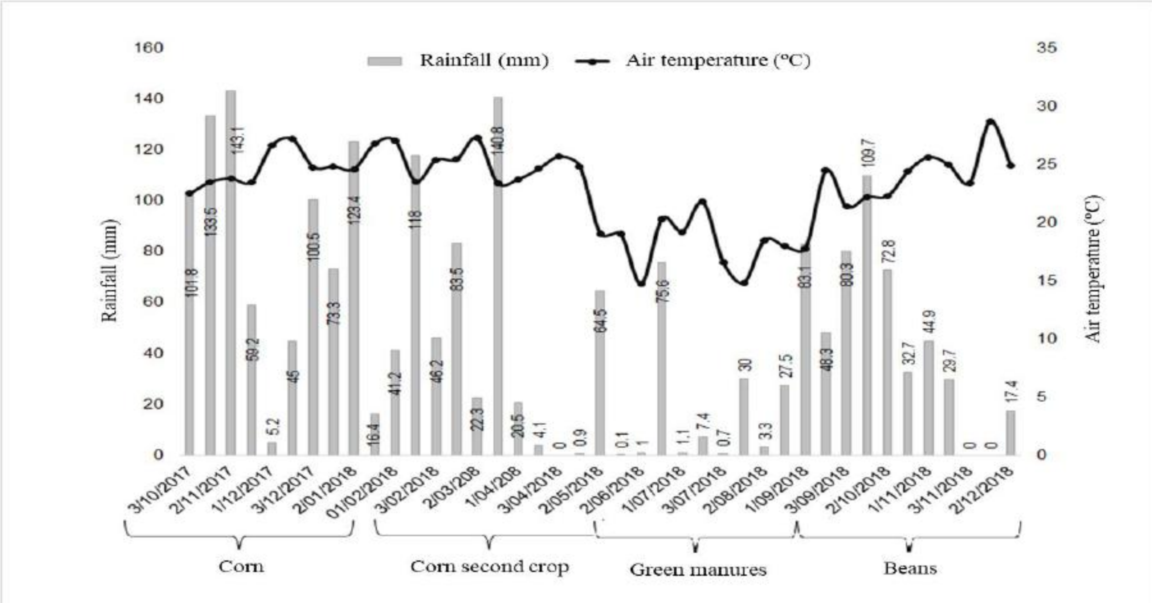
Figure 1 - Cumulative monthly rainfall data in millimeters (mm) and the average temperature in degrees Celsius (°C) between October 20, 2017, and December 30, 2018.



Source: Automatic weather station in Medianeira - PR, UTFPR in partnership with IAPAR.

Experimental design, implementation, and conduction

The trials were conducted during the 2017/2018 and 2018 agricultural seasons. The experimental design used was in randomized blocks, with five repetitions. Each plot had 30 m^2, and 0.5 meters of borders and side rows were deducted to determine the useful area. The treatments consisted of four different crop rotation systems: 1 - Monocrop corn/monocrop corn/fallow/beans, 2 - Consortium of corn + cowpea/ monocrop corn/oats/beans, 3 - Consortium of corn + crotalaria/ monocrop corn/forage radish/beans and 4 - Consortium of corn + jack bean/ monocrop corn/vetch/beans.

In spring/summer 2017/2018, corn for silage (harvest) was grown in a consortium with the green manures; in fall/winter/2018, corn (second crop) in monocrop was under the green manures' straw. After the harvested corn was removed, the winter/spring green manures were sown: forage radish, vetch, and oats. The bean crop was sown under this straw in September. The dry matter yields of corn for silage in each growing season (spring/summer and fall/winter) and of beans were evaluated, as well as the total productivity of the system in the two years of evaluation.

We also evaluated the straw productivity, considering the residual dry matter of spring-summer corn, fall-winter corn, spring/summer green manures, and winter/spring green manures. The straw productivity of the bean plant was not evaluated.

Before planting the experiment, a light harrow was carried out to eliminate the initial population of spontaneous plants and uniform the soil surface. Based on the chemical analysis of the soil, 1 kg m^{-2} of cured poultry litter was applied to the soil when sowing the corn crop. The analyses of the average chemical composition of the poultry litter were performed in the Environmental and Instrumental Chemistry Laboratory of UNIOESTE and contained: pH in water = 7.40; Total carbon = 411 g kg^{-1}; O.M = 820 g kg^{-1}; Total N = 44 g kg^{-1}; P = 8.50 g kg^{-1}; K = 37 g kg^{-1}; Ca = 31 g kg^{-1}.

Sowing of spring/summer (harvest) corn was performed on October 29th, 2017, and fall/winter (second crop) on February 17th, 2018. The cultivar used was INCAPER 203, sown with a manual sowing machine at an inter-row spacing of 0.90 m, with a plant population of 55 and 50 thousand ha^{-1}, respectively.

The green manures cowpea (*Cajanus cajan*), Crotalaria spectabilis (*Crotalaria spectabilis*), and Jack bean (*Canavalia ensiformis*) were sown in between the rows of spring/summer corn, with the help of a hand sowing machine, on the same date as the corn was sown, using 90, 40, and 50 kg seeds ha^{-1} respectively.

After the harvested corn was removed, the plots containing the green manures were mowed with a motorized mower to form mulch. Sowing of second crop corn (fall/winter) was in the no-till system, seven days after cutting the green manures, with manual soil tillage, only in the planting line.

On April 6th, 2018, after harvesting the second crop of corn, the plots were weeded, and the winter/spring green manures were sown. The following sowing density was used: oats (*Avena sativa*) 60 kg seeds ha^{-1}, forage radish (*Raphanus sativus*) 50 kg seeds ha^{-1}, and vetch (*Vica sativa*), 80 kg seeds ha^{-1}. After 108 days from sowing, the winter green manures were mowed with a motorized brush cutter to form a straw. The black bean cultivar IPR Gralha was sown over the straw.

On September 22nd, 2018, a no-till system, using a hand sowing machine and a 0.45 m row spacing, with a population of 222,000 plants ha^{-1}.

The crop management performed during the experimental period for corn was the application of "supermagro" biofertilizer 3%, 15, 35, and 45 days after corn seeding; control of cartridge caterpillars with the biological insecticide Dipel, based on *Bacillus thuringiensis*, var. *kurstaki*, line HD-1, applied at the dose recommended by the manufacturer. In the plots where there were corn/corn/fallow/beans, manual weeding was performed during the fallow period two to reduce the population of spontaneous plants.

The bean crop received a 3% "Supermagro" biofertilizer application in 3 applications: 20 days after sowing, flowering, and pod formation.

Sample collection and determination of the silage dry mass productivity of corn and bean grains from different production systems

The production of silage mass was evaluated in the corn crop when the crop reached the phenological stage from pasty grain to too hard floury (2/3 of the milk line). Four meters of each row of the plots were collected by manual cutting at the height of 40 cm from the ground. The material was chopped with the help of a foraging machine, weighed to determine the wet mass, and then dried in a forced circulation oven at 55ºC until it reached a constant weight. When cutting, the number of plants per meter was counted to estimate the final plant population and the dry mass productivity per ha^{-1}, calculated in Mg ha^{-1} (Moreira et al., 2014).

The bean yield was determined by harvesting the beans from the whole useful area of each plot when the crop presented 13 to 15% humidity. The harvest and threshing were performed manually. Through the mass of grains produced in the plot and correction of the moisture to 13%, the productivity was estimated in t ha^{-1}.

Sample collection and straw determination from the different production systems

The samples for determining the productivity of corn straw in both crops were taken at the time of cutting corn for silage. As well as for the spring/summer green manures; the winter/spring ones at 108 days after emergence according to methodology adapted from Baghdadi et al. (2016).

An empty square was used for this evaluation, with a sample area equivalent to 0.25 m^2, randomly placed at 3 points of each plot. The plants inside were cut with the help of pruning shears and separated between corn straw (the rest of the stalk and leaves) and green manure straw. The samples of each treatment were weighed, placed in paper bags, and taken to a forced air circulation oven at a temperature of 55ºC (± 2ºC) for 72 hours. When the material was removed, it was weighed to determine the dry mass and estimate in t ha^{-1}.

Statistical analysis

The data obtained were tabulated and analyzed for normality and homogeneity using Lilliefors (Kolmogorov-Smirnov) tests. Then, they were submitted to variance analysis considering a significance level of 5% for the F test and to the multivariate method using principal component analysis.

The principal components analysis allows condensing the most significant amount of the original information in p variables (p=11, in this study) into two variables not correlated with each other, called principal components. In this study called CP1 and CP2, each of these components, which together form a new two-dimensional space, is a linear combination of the original variables, with the capacity to retain the most significant amount of information possible. This way, the initial set of variables is characterized by two new variables, which enables their ordering in a two-dimensional figure.

All statistical analyses were processed by the statistical software Genes (Cruz, 2006).

3. Results and Discussion

There was a significant effect ($p< 0.05$) of crop rotation systems for the variables corn dry matter productivity for spring/summer silage, bean productivity, and total productivity of the systems (Table 2).

The lowest corn productivity for spring/summer silage was observed in the monocrop corn modality, while the highest productivity was observed in the corn+jack bean intercrop, with an average increase of 21%. The intercropping of corn, and the monocrop corn grown in succession with hog beans, favored the total productivity of the system, which obtained 37.82 Mg ha^{-1} (Table 2).

Table 2 - Dry matter productivity corn for silage and bean yield in different seasons and cropping modalities (rotation systems) under agroecological production management.

	Dry matter productivity (t ha^{-1})			
Modalidades de cultivo (Sistemas de rotação)	Corn for silage spring/summer	Corn for silage fall/winter	Bean yield	Total corn silage and bean yield
1- Monocrop corn/monocrop corn/fallow/beans	13,64 b	17,09^{ns}	0,82 d	31,54 b
2- Consortium of corn + cowpea/ monocrop corn/oats/beans	15,03 ab	18,64^{ns}	1,87 a	35,54 ab
3- Consortium of corn + crotalaria/ monocrop corn/forage radish/beans	14,19 ab	19,32^{ns}	1,51 b	35,01 ab
4- Consortium of corn + jack bean/ monocrop corn/vetch/beans	18,04 a	18,66^{ns}	1,12 c	37,82 a

*ns: not significant by Tukey test at 5% probability. **Mediums followed by equal lowercase letters in the column do not differ by the Tukey test at 5% probability. Source: Authors.

The increased productivity observed with the jack bean may be associated with the high biological fixation of N performed by this green manure. It can fix between 37 to 280 kg ha^{-1} of N per year. Besides promoting the release of other nutrients in synchrony with the demand of the crop, such as K, P, and Mg, it also presents rustic cotyledonary leaves that are resistant to water deficit; and a deep root system, which competes with spontaneous plants for space, light, and nutrients (W. P. de Carvalho et al., 2013; S. P. Coelho et al., 2016; Paz et al., 2019).

According to Heinrichs et al. (2002) and Queiroz et al. (2010), the cowpea increases the system's productivity with the increase of the cultivation period because a large amount of dry matter mass contributes to greater availability and recycling of nutrients to crops in succession.

In the studies carried out by Collier et al. (2011); Heinrichs et al. (2002); Queiroz et al. (2010), and Spagnollo et al. (2002), the best system yields were also obtained in intercropping and successive crops to the pigeon pea compared to traditional monocropping.

The green manures cultivated during winter/spring positively influenced bean productivity. The highest yield was observed in the corn + cowpea/corn monocrop/pea mode of cultivation (Table 2).

Black oats produce high amounts of dry matter mass, which allows good soil coverage and nutrient cycling (Aita & Giacomini, 2003; Mattei et al., 2018). Its decomposition is slower in the soil when compared to forage radish and vetch, which allows it to protect and maintain soil moisture longer (Ceretta et al., 2002; Seidel et al., 2012).

The climatic conditions observed in this study were not favorable for obtaining high yields in the bean crop (Figure 1). However, the values of this study were higher than those obtained by Seidel et al. (2011) and Steiner et al. (2009) in similar climatic conditions, which found productivity ranging from 1.20 to 1.39 Mg ha^{-1}.

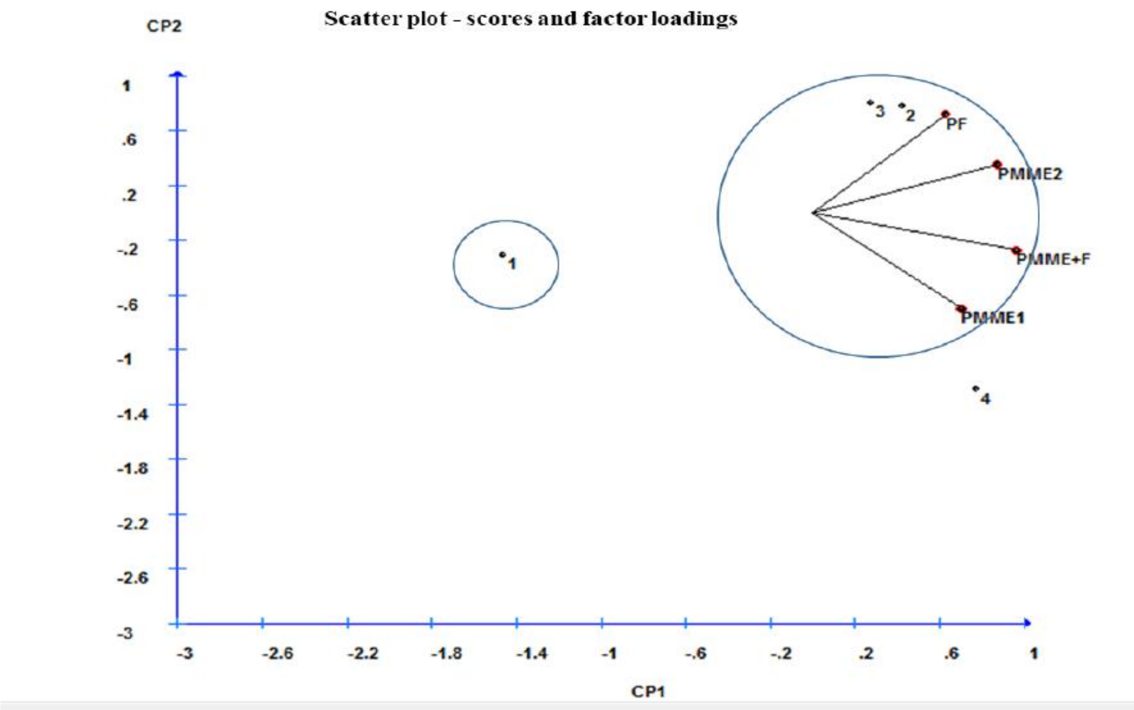
The results of this study corroborated with Bittencourt et al. (2009); Crusciol et al. (2007); Evans et al. (2016), and Seidel et al. (2012), who obtained higher yields for bean plants grown in succession to black oats.

The data in Table 2 referred to the rotation systems' dry matter productivity, and the principal component analysis (PCA) was performed. This analysis allowed the distribution of corn's dry matter productivity variables for silage and beans in the different cropping modalities in two principal components (CP1 and CP2).

The principal components (CP1 and CP2) collectively allowed the cropping modes' two-dimensional dispersion in a Biplot plot (Figure 2). The total information of the original data retained by the two components was 94.47% of the total variation. CP1 was responsible for explaining 64.35% of the results and CP2 for 30.11%.

These results are by the criteria established by Sneath & Sokal (1973), in which the number of principal components (PC) used in the interpretation must be such that it explains at least 70% of the total variance of the data.

Figure 2 - Biplot CP1 versus CP2 on corn's dry matter productivity characteristic for silage and beans in different modalities and cropping seasons under agroecological production management. 1 - Monocrop corn/monocrop corn/fallow/beans; 2 - Consortium of corn + cowpea/ monocrop corn/oats/beans; 3 - Consortium of corn + crotalaria/ monocrop corn/forage radish/beans and 4 - Consortium of corn + jack bean/ monocrop corn/vetch/beans. PMME1: Corn yield for spring/summer silage; PMME2: Corn yield for autumn/winter silage; PF: Bean yield; PMME+F: Total corn yield for silage and beans.



Source: Authors.

For CP1, the highlights were total corn productivity for silage and beans (PMME+F) with a weighting coefficient of 0.59 and corn productivity for autumn/winter silage (PMME2) with a weighting coefficient of 0.54.

In the second principal component (CP2), bean productivity (FP) stood out with 0.65, followed by corn productivity for spring/summer silage (PMME1) with a -0.64 weighting coefficient (Table 3).

The variables with the highest weight in CP1 present similar behavior for the modes with green manures. Contributing to the isolation in the Biplot, mode 1, where the rotation was: monocrop corn/monocrop corn/ fallow/beans, there was no green manure cultivation in this system (Figure 2). This mode obtained the lowest total productivity, 31, 54 Mg ha-1 (Table 2); that is, the modes with green manures obtained an average increase in total dry matter productivity of corn for silage and beans of 14%.

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Table 3 - Coefficient weighting of dry matter productivity traits of corn for silage and beans grown under agroecological production management with the first two principal components.

Parameter	Coefficient weighting	
	CP1	CP2
Corn silage spring/summer	0,4379	-0,6381
Corn for silage fall/winter	0,5441	0,3176
Bean yield	0,3915	0,6552
Total corn silage and bean yield	0,5991	-0,2503

Source: Authors.

What may have contributed to the increased production in the areas with green manures was the biological fixation and transfer of nitrogen; and increased availability of other essential nutrients for the crops of interest. Green manures can also suppress spontaneous plants, protect the soil from erosion, maintain moisture, and reduce the temperature oscillation and amplitude at the soil surface (Kappes, 2011; Martinez et al., 2019; Moraes et al., 2016; Seidel et al., 2012).

The second highlight of CP1 was the corn dry matter yields for autumn/winter silage, obtained under the corn straw intercropped with cowpea, crotalaria, and Jack bean. However, on the crotalaria straw, the corn dry matter productivity for autumn/winter silage (PMM2) was higher, with an average of 19.32 Mg ha^{-1}(Table 2).

The increase in productivity may result from the closer C/N ratio that occurs in intercrops of grasses and legumes compared to monocrop grasses, allowing a rapid decomposition of the crop residues, making nitrogen and other nutrients available to subsequent crops (Andreola et al., 2000).

In addition, crotalaria presents a high allelopathic activity that reduces weed competition with the crop of commercial interest. It also incorporates around 150 to 450 kg ha^{-1} of N per year into the productive system, which can favor the productivity of corn in succession (M. A. C. de Carvalho et al., 2004; Martinez et al., 2019; Paz et al., 2019). Corroborating with the results, the works conducted by Brito et al. (2017), Chieza et al. (2017), and Queiroz et al. (2010) also showed higher yields of corn grown in winter under crotalaria straw.

The highlights of CP2 showed that the corn + cowpea/corn monocrop/oats/bean and corn + crotalaria/corn monocrop/forage radish/bean cultivation modes show the best results for bean productivity. With yields of 1.87 and 1.51 t ha^{-1}, respectively (Table 2).

Oats and forage radish are green manures capable of extracting nutrients from deeper soil layers through their root system and providing high soil coverage; in addition, they have a higher C/N ratio than vetch, which allows less decomposition, favoring greater coverage, protection against erosion and maintenance of soil moisture (Debiasi et al., 2017; Mattei et al., 2018).

However, for the productivity of corn silage spring/summer, the cultivation modes of corn + cowpea/corn monocrop/beans and corn + crotalaria/corn monocrop/forage radish/beans; present a reduction in productivity (Table 2 and Figure 2), showing that there was a competition of these green manures with the corn crop for silage. This is because the cowpea and crotalaria have an immediate initial occupation and tall size; therefore, they provide more shade to corn, increasing competition for water, light, and nutrients (Almeida & Câmara, 2011).

There was a significant effect ($p< 0.05$) of the different crop rotation systems on straw to soil productivity (Table 4).

The crop rotation system composed of corn + jack bean/corn monocrop/vetch showed the best straw productivity of green manures in the soil, about 7.40 t ha^{-1}. The jack bean produced the most significant proportion of this straw in the spring/summer crop; this growing season promoted an average increase of 37% of straw compared to the other green manures

(Table 4).

The straw left by cover crops in the soil added to the residues of commercial crops in succession or rotation promotes the recovery, maintenance, and/or improvement of chemical, physical and biological properties. Thus, a favorable environment for plant growth is developed, contributing to the stabilization of agricultural production, soil sustainability, and less dependence on external inputs to agroecosystems (Moraes et al., 2016; Redin et al., 2016).

Similar results were observed by Almeida and Câmara (2011), Carvalho et al. (2013), and Padovan et al. (2013), who also obtained higher straw production in crops containing these green manures.

The lowest deposition of straw on the soil was observed in the monocrop/monocrop corn/fallow mode over the crop cycles. During the fall/winter crop, the traditional monocrop showed an average loss of 31% of straw on the soil (Table 4).

The only source of straw in this crop rotation system was corn straw. Therefore, these results were already expected and negatively influenced the variables of total corn straw accumulation and total straw accumulation in the system.

The absence of conservationist practices such as crop rotation and stubble deposition for protection and nutrient replacement limits the full development of crops and compromises the sustainability of the productive system throughout the crops (Chioderoli, de Mello, et al., 2012; Mottin et al., 2018).

The average productivity of total stubble of corn plus green manures for the cultivation modalities containing green manures in its composition was 16.59 t ha^{-1}, while for the modality corn in monocrop/monocrop/fallow was 8 t ha^{-1}, evidencing an average gain of 100% in the stubble productivity. In each growing season, the average straw yield in the systems where the green manures were present was, on average, 8 t ha^{-1}; in the monocrop was 4 t ha^{-1} (Table 4).

These results are in agreement with Padovan et al. (2013), Queiroz et al. (2010), and Seidel et al. (2012), who obtained the lowest residual dry matter productivity for the soil when corn was grown in monocrop.

According to Kluthcouski et al. (2004) and Seidel (2016), in the southern region of Brazil, the straw production contributed to the soil for good maintenance of the no-till farming system should be between 7 and 8 t ha^{-1} in each crop. Therefore, over time, this cropping system 1: monocrop/corn monocrop/fallow, may lead to a reduction in soil organic carbon, leading to degradation of the production system (Schiller et al., 2018).

Table 4 - Straw yield in corn's different seasons and cropping modes (rotation systems) for silage and green manures grew under agroecological production management.

Straw yield (t ha^{-1})							
Cropping modes (Rotation systems)	Corn spring/summer	Green manures spring/summer	Corn fall/winter	Winter green manures	Total corn	Total green manures	Total corn and green manure
1- Monocrop corn/monocrop corn/fallow/beans	3,76^{ns}	-----	4,51b	-----	8,28b	-----	8,28b
2- Consortium of corn + cowpea/monocrop corn/oats/beans	4,11 ^{ns}	4,60ab	6,74a	1,33^{ns}	10,85a	5,93b	16,79^{a}
3- Consortium of corn + crotalaria/ monocrop corn/forage radish/beans	3,79 ^{ns}	3,69ab	6,53a	1,45^{ns}	10,33a	5,15b	15,47^{a}
4- Consortium of corn + jack bean/ monocrop corn/vetch/beans	3,66 ^{ns}	6,58a	6,46a	0,82^{ns}	10,12a	7,40a	17,52^{a}

*ns: not significant by the Tukey test at 5% probability. **Mediums followed by equal lowercase letters in the column do not differ by the Tukey test at 5% probability. Source: Authors.

With the data on the amount of straw produced in the different seasons and cultivation modes presented in Table 4, the principal component analysis (PCA) was performed. This analysis allowed the distribution of the variables into two principal components (CP1 and CP2).

The principal components (CP1 and CP2) collectively allowed the cropping modes' two-dimensional dispersion in a Biplot plot (Figure 3). The total information of the original data retained by the two components was 96.48%, with CP1 having 79.64% and CP2 retaining 16.84% (Table 5).

The variables that stood out from the first principal component (CP1) for the amount of straw by order of importance were: fall/winter corn (MSM2) with a 0.42 weighting coefficient; total corn plus green manures (MSM+AV), and total corn (MSRM) with 0.41; total green manures (MSRAV) 0.40; spring/summer green manures (MSAV1) and winter/spring green manures (MSAVS) with 0.38 (Table 5).

In the second principal component (CP2), the highlight was the corn stover productivity for spring/summer silage (MSM1) with a 0.83 weighting coefficient (Table 5).

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Table 5 - Coefficient weighting of corn straw for silage and green manures grown under agroecological production management with the first two principal components.

Parameter	Coefficient weighting	
	CP1	CP2
Corn spring/summer	0,1434	0,8382
Green manures spring/summer	0,3819	-0,3515
Corn fall/winter	0,4220	0,0289
Green manures winter/spring	0,3798	0,2431
Total corn	0,4158	0,1727
Total green manures	0,4052	-0,2512
Total corn and green manures	0,4173	-0,1448

Source: Authors.

The straw yields of the modes containing green manures had the same behavior for CP1. They were also responsible for isolating in the Biplot the cultivation mode 1: monocrop corn/monocrop corn/fallow and indicating that this cultivation mode does not prioritize the accumulation of straw on the soil (Figure 3 and Table 4).

For Claro (2001) and Primavesi (2002), bare soils become chemically and physically unbalanced, besides being biologically inactive. Therefore, good straw productivity results in greater nutrient availability and soil coverage, consequently greater productivity of subsequent crops (Pacheco et al., 2011; TORRES et al., 2014).

The highlight of CP2 indicates that corn intercropped with cowpea favored the accumulation of corn stover in spring/summer (Figure 3). The cutting of corn for silage exports most of the aerial portion, leaving residue for the soil portions of the stalk below the cutting line.

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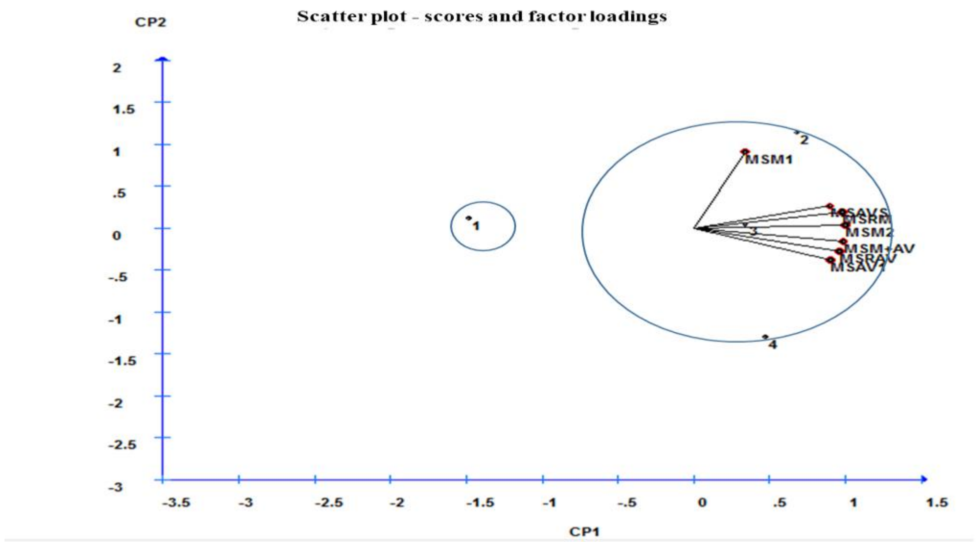
Figure 3 - Biplot CP1 versus CP2 on the straw characteristic in different cultivation modalities of corn for silage and green manures grew in agroecological area. 1 - Monocrop corn/monocrop corn/fallow; 2 - Consortium of corn + beans - cowpea/monocrop corn/oats; 3 - Consortium of corn + crotalaria/monocrop corn/forage radish and 4 - Consortium of corn + Jack bean/monocrop corn/vetch. MSM1: Spring/summer corn; MSAV1: Spring/summer green manures; MSM2: Fall/winter corn; MSAVS: Winter/spring green manures; MSRM: Total corn; MSRAV: Total green manures, MSM+AV: Total corn plus green manures.



Source: Authors.

Stem diameter is susceptible to intra- and interspecific competition, i.e., it is sensitive to population changes and competition with plants in the rows and between rows; therefore, the cowpea possibly did not influence the traits that promote the reduction of stem diameter, allowing more significant accumulation of straw from corn on the soil in this cropping mode (Coelho et al., 2016; Martinez et al., 2019).

4. Conclusion

The crop rotation systems that included green manures showed the highest total dry matter productivity of corn for silage and beans. With emphasis on the modality corn + Jack bean / corn monocrop / vetch / beans.

The intercropping with cowpea favored the productivity of corn in the harvest and the crotalaria stover favored the productivity in the second crop. The systems corn + cowpea/corn monocrop/oat/beans and corn + crotalaria/corn monocrop/forage radish/beans favored the productivity of beans.

The monocrop/monocrop/fallow mode did not prioritize the accumulation of straw on the soil.

New studies involving crop rotation systems that include the use of different green manures in corn for silage production systems aiming at improving the agronomic efficiency of the cropping system and the improvement of soil physical-chemical characteristics should be developed in future research.

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