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Components of corn crop yield under inoculation with *Azospirillum brasilense* using integrated crop-livestock system

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ABSTRACT. The objective of this study was to evaluate the agronomic characteristics of corn seed inoculated with *Azospirillum brasilense*, grown on black oat and ryegrass straw, and managed under different grazing strategies and doses of nitrogen. The experiment was conducted in Santa Maria, Rio Grande do Sul State, Brazil, during two agricultural seasons (2012/2013 and 2013/2014) in a randomized, complete block design with three replications. In the winter period, black oat and ryegrass straw were managed at different grazing heights by sheep (0.30, 0.20, 0.10 m, conventional grazing, and no grazing) with three doses of nitrogen (0, 50, and 100 kg ha^{-1}, with or without inoculation by *A. brasilense*). We used the hybrid Pioneer (P1630H®) in 2012 and the hybrid Agroeste (AS 1551®) in 2013. The height of corn plants was greater when they were grown on black oat and ryegrass straw, and the absence of grazing favored productivity. Under drought conditions, the application of nitrogen to the pasture favored corn development, increasing plant height, ear height, and stem diameter. Inoculation with *A. brasilense* had a positive effect on the characteristics of yield and productivity of corn, independent of growing season and hybrid used.

Keywords: *Zea mays*, grazing heights, biological nitrogen fixation, nitrogen, integrated systems.

Componentes do rendimento da cultura do milho sob inoculação de *Azospirillum brasilense* em sistema de integração lavoura-pecuária

RESUMO. Objetivou-se, com este trabalho, avaliar as características agronômicas da cultura do milho sob inoculação de sementes com *A. brasilense*, cultivado sobre palhada de aveia-preta e azevém manejada com diferentes manejos de pastejo e doses de nitrogênio. O experimento foi conduzido em Santa Maria, Brasil, em dois anos agrícolas (2012/2013 e 2013/2014), em delineamento experimental de blocos casualizados, com três repetições. No período hibernal a pastagem de aveia preta e azevém foi manejada em diferentes alturas de pastejo (0,30, 0,20, 0,10 m, pastejo convencional e sem pastejo) por ovinos, três doses de N (0, 50 e 100 kg ha^{-1}, com ou sem inoculação de *A. brasilense*). Foi utilizado o híbrido Pioneer (P1630H®) em 2012 e o híbrido Agroeste (AS 1551®) em 2013. A altura das plantas de milho é beneficiada quando é cultivado sobre palhada de aveia preta e azevém na ausência de pastejo, favorecendo também a produtividade. Sob déficit hídrico o nitrogênio aplicado na pastagem favorece o desenvolvimento do milho, aumentando altura da planta e de inserção de espiga e diâmetro de colmo. A inoculação com *A. brasilense* tem efeito positivo sobre os componentes do rendimento e produtividade do milho independente do ano agrícola e do híbrido utilizado.

Palavras-chave: *Zea mays*, alturas de pastejo, fixação biológica de nitrogênio, nitrogênio, sistemas integrados.

Introduction

The integrated crop-livestock system (ICL) aims to achieve high animal and grain productivity within the same year and seeks to be sustainable over time (Sandini et al., 2011). In this system, the corn crop (*Zea mays*) stands out due to its various applications for both animal and human consumption and for its ability to generate income through the sale of surplus production.

In southern Brazil, ICL is characterized by the use of pastures to cultivate animal feed, such as a mixture of black oat and ryegrass, during the winter period and crops for the production of grains and legumes, such as corn and soybeans, in the summer period. Thus, pasture management is a key factor for both animal husbandry and the production of commercially important crops (Nicoloso, Lanzanova, & Lovato, 2006). In this system, one of the biggest concerns of grain producers is the potential for soil compaction by animal trampling in pasture areas, which can also result in a reduction in the amount of crop residue that is left as ground cover due to grazing and can negatively impact the production of grain crops grown in succession.

Nicoloso et al. (2006) stated that a high winter grazing pressure limits the productivity of soybean and corn grown in succession. Macari et al. (2011) found that grazing sheep in an area with ryegrass did not affect the productivity of corn and soybean grown in succession, regardless of the intensity and grazing method used. Tracy and Zhang (2008) found not only that the presence of cattle in agricultural areas did not negatively affect soil properties and corn productivity in a five-year trial period but also that their presence conferred benefits, such as improved soil quality, due to the increased organic matter and reduced animal feeding costs during the winter.

Nitrogen (N) fertilization should also be considered in this system because the application of nitrogen to pastures provides greater biomass production and allows for a more uniform distribution of forage and a greater production cycle (Heringer & Moojen, 2002). In addition, nitrogen is one of the nutrients that have the greatest effects on the increase in grain productivity in corn agronomy. In ICL, the application of certain quantities of nitrogen to pastures has residual effects for the subsequent culture, even allowing for the discontinuation of nitrogen application to the corn crop (Assmann et al., 2003; Novakowiski et al., 2011). In contrast, nitrogen fertilization is an important economic and environmental issue because the profitability of the production system is greatly influenced by the high cost of nitrogen use and because excessive application increases nitrate concentrations in the soil and causes groundwater pollution (Berenguer, Santiveri, Boixadera, & Lloveras, 2009).

Part of the nitrogen that is required by grasses can be supplied by biological nitrogen fixation through the association between plants and growth-promoting bacteria, such as the bacterium *Azospirillum brasilense*. These bacteria can promote plant growth either by biological nitrogen fixation or by producing substances that aid in root growth, such as indoleacetic acid (Moreira, Silva, Nóbrega, & Carvalho, 2010). Calculations of the contribution of biological nitrogen fixation by associative bacteria to grasses are approximately 25–50 kg N ha^{-1} $year^{-1}$, which is equivalent to the average supply of approximately 17% of the demand of crops such as rice, wheat, and corn (Moreira et al., 2010), representing savings in production costs and a more rational use of inputs.

The objective of this study was to evaluate the effects of the presence of black oat and ryegrass straw at different grazing heights, varying doses of nitrogen, and seed inoculation with *A. brasilense* on the production characteristics of corn in a crop-livestock integrated system.

Material and methods

The experiment was conducted during two growing seasons (2012/2013 and 2013/2014) in Estância Velha, Monte Boca District, in the municipality of Santa Maria in the central region of Rio Grande do Sul State, Brazil, which has the geographic coordinates 29° 41' 51.07"S and 54° 02' 30.42 "W and an altitude of 195 m. The climate of the region is classified as Cfa (humid subtropical) according to the Köppen–Geiger system (Nimer, 1989). The area that was used for the experiment was approximately 0.36 ha of an integrated crop-livestock system, and the pasture was formed by a consortium of black oat and ryegrass during the winter period and of corn during the summer period. Prior to the installation of the experiment, the area had been used with ryegrass during the winter period for feeding sheep. In the summers of 2011 and 2012, millet crop was used for beef cattle grazing.

The soil of the experimental site is classified as Paleudalf (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2006), and its chemical analysis showed the following results: pH ($CaCl_2$) = 4.10; Organic Matter = 21.44 g dm^{-3}; P= 1.79 mg dm^{-3}; K = 0.80 $cmol_c$ dm^{-3}; Cu = 1.19 mg dm^{-3}; Fe = 175.78 mg dm^{-3}; Zn = 1.36 mg dm^{-3}; Mn = 118.23 mg dm^{-3}; Al^{3+} = 0.96 $cmol_c$ dm^{-3}; H+Al = 6.21 $cmol_c$ dm^{-3}; Ca = 1.82 $cmol_c$ dm^{-3}; Mg = 1.13 $cmol_c$ dm^{-3}; SMP index = 5.70; SB = 3.75 $cmol_c$ dm^{-3}; V = 37.65%; and Sat. Al = 20.38%.

The winter pasture consisted of a mixture of black oat and ryegrass in the following proportion: 75% black oat seeds and 25% ryegrass seeds. Sowing took place on May 17 in both 2012 and 2013. In 2012, common cultivars were utilized, and both oat and ryegrass were purchased locally in Santa Maria. In 2013, the black oat IAPAR 61 and ryegrass BRS Ponteio cultivars were utilized. The number of seeds that were suitable per square meter was 400 (300 black oat + 100 ryegrass), and this value was corrected according to the germination rates of the seed lot. Sowing was carried out manually by throwing, and the seeds were incorporated by light harrowing. The two treatment groups of black oat and ryegrass seeds were submitted (or not) to inoculation with the bacterium *A. brasilense* (Abv5 and Abv6 strains) using 2 mL of the commercial-brand liquid inoculant "AZO TOTAL" to approximately 250 g of the black oat + ryegrass mixture (concentration of 2×10^8 colony-forming units per milliliter of product). Inoculation was performed in the morning and sowing in the afternoon during both years.

As for grazing management, the black oat + ryegrass pasture was managed as follows: (a) conventional grazing (CG), where the animals remained in the pasture throughout the trial without controlling the pasture height; (b) height of the pasture in the animal exit area kept at 0.30 m (A30); (c) height of the pasture in the animal exit area kept at 0.20 m (A20); (d) height of the pasture in the animal exit area kept at 0.10 m (A10); and (e) no grazing (NG). Regarding the management of nitrogen fertilization, all thirty of the experimental units were managed as follows: (a) without nitrogen fertilization (0 kg ha^{-1}), (b) 50 kg ha^{-1} nitrogen, and (c) 100 kg ha^{-1} nitrogen.

On 26 October 2012 and 28 November 2013, black oat and ryegrass were dried out with a glyphosate-based herbicide at a dose of 3.0 L ha^{-1}. On these two dates, bulk samples of black oat forage and ryegrass were collected from each plot to obtain the amount of residue remaining in the area for the different forms of management applied in winter. Bulk quantities were obtained by cutting close to the ground with scissors in an enclosed area measuring 0.25 m^2. The cut samples were placed in paper bags, dried to a constant mass in a forced ventilation oven at 60°C, and weighed, and the residual dry mass (DM) in kilograms per hectare (kg ha^{-1}) was calculated. In 2012, the residual forage masses were 3,287, 2,247, 2,088, 1,723, and 1,186 kg DM ha^{-1} for the four NG treatments 0.30 m, 0.20 m, 0.10 m, and CG, respectively. In 2013, the residual forage masses were 4,146, 2,414, 2,252, 1,277, and 1,182 kg DM ha^{-1} for the four NG treatments 0.30 m, 0.20 m, 0.10 m, and CG, respectively.

Each plot was 16 m^2 (4 × 4 m). Direct corn seeding was performed on 16 November 2012 and 1 December 2013. The hybrid Pioneer P1630H was used in 2012 and the hybrid Agroeste AS 1551 in 2013. For the corn crop, we used four rows that were spaced 0.90 m, totaling 60,000 seeds ha^{-1}. In two rows, seeds were inoculated with the bacterium *A. brasilense* (Abv5 and Abv6 strains) at a concentration of 2 × 10^8 colony-forming units per milliliter of product (5 ml of liquid inoculant "AZO TOTAL®" kg^{-1} seed). In the remaining two rows, the seeds were not inoculated. For basic fertilization, 350 kg ha^{-1} of an NPK (05-20-20) fertilizer was used. The other applied agricultural practices were carried out according to the technical recommendations for corn. Nitrogen was not applied to the corn.

In both growing seasons prior to harvest, plant height assessments (ear height and stem diameter) were determined. To measure plant height, three plants in each plot were assessed at random. The plant height (PH) corresponded to the distance measurement from the ground to the insertion of the tassel. The first ear height (FEH) corresponded to the measurement from the ground to the node that was inserted into the lower ear. The stem diameter (SD) was measured at 0.20 m aboveground using a digital caliper.

Harvest took place after the plants attained physiological maturity (30% moisture). All of the ears in each plot were collected. Measurements of (a) ear diameter (ED) using calipers, (b) ear length (EL) using a numbered ruler, (c) number of grains per row (NKR), and (d) number of kernel rows per ear (NR) were taken from five randomly separated ears in each plot. To evaluate productivity, all of the ears of a given plot were threshed, the grain was weighed, the values were corrected to 13% moisture content, and data were expressed in kilograms per hectare (kg ha^{-1}). Subsequently, the mass of one hundred grains was estimated, and the data were expressed in grams (corrected to 13% moisture content).

Statistical analyses to test for significant differences among groups were performed using an analysis of variance (ANOVA). Significant data were further analyzed to compare means with Duncan's multiple range test with a 5% probability of error. For these analyses, we used the statistical software SOC (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 1997).

Results and discussion

In the two agricultural years that were evaluated in this study, 2012/2013 and 2013/2014, there was no interaction of grazing management × doses of N × inoculation with PH, FEH, and SD, requiring the further elucidation of the individual effects of each treatment (Table 1). During the 2012/2013 agricultural year, the height of corn plants was affected by different grazing techniques and inoculation with *A. brasilense* but was not influenced by the levels of nitrogen applied to the pasture.

Corn plants were taller in areas that were not grazed (NG) than in areas in which other grazing management strategies were implemented during the two growing seasons. This result can be explained by the increased amount of residual dry mass of black oat and ryegrass in the NG treatment group (Table 1), which may have helped maintain soil moisture for longer, thus favoring growth. In the 2013/2014 agricultural year, the difference in the height of corn plants was more pronounced due to the different grazing techniques. This result can be attributed to the longer dry period during the development of the corn crop and on the differences between the residual dry mass of black oats and ryegrass depending on the post-grazing sward heights. As a result of low residual dry mass, soil protection could be compromised, especially under adverse environmental conditions, such as a lack of moisture and high temperature.

Table 1. Plant height (PH), first ear height (FEH), and stem diameter (SD) in corn plants during the 2012/2013 and 2013/2014 agricultural years.

Agricultural year 2012/2013			
Grazing management	PH (m)	FEH (m)	SD (m)
NG	1.92 a*	1.04	0.0232
0.30 m	1.84 b	1.04	0.0234
0.20 m	1.85 b	1.05	0.0236
0.10 m	1.84 b	1.04	0.0229
CG	1.86 b	1.07	0.0235
Doses of N in pasture	PH (m)	FEH (m)	SD (m)
0 kg ha^{-1}	1.86	1.05	0.0232
50 kg ha^{-1}	1.86	1.04	0.0235
100 kg ha^{-1}	1.86	1.05	0.0234
Inoculation (corn)	PH (m)	FEH (m)	SD (m)
With *Azospirillum*	1.87 a	1.03 b	0.0232
Without *Azospirillum*	1.85 b	1.06 a	0.0235
Average	1.86	1.04	0.0234
CV (%)	3.61	5.53	8.01
Agricultural year 2013/2014			
Grazing management	PH (m)	FEH (m)	SD (m)
NG	1.85 a	1.12 a	0.0228 a
0.30 m	1.74 b	1.09 ab	0.0216 b
0.20 m	1.68 c	1.05 b	0.0213 bc
0.10 m	1.57 d	0.94 c	0.0207 bc
CG	1.45 e	0.90 c	0.0210 c
Doses of N in pasture	PH (m)	FEH (m)	SD (m)
0 kg ha^{-1}	1.61 b	0.99 b	0.0211 b
50 kg ha^{-1}	1.67 a	1.04 a	0.0214 ab
100 kg ha^{-1}	1.68 a	1.03 a	0.0219 a
Inoculation (corn)	PH (m)	FEH (m)	SD (m)
With *Azospirillum*	1.72 a	1.05 a	0.0228 a
Without *Azospirillum*	1.59 b	0.99 b	0.0202 b
Average	1.66	1.02	0.0215
CV (%)	7.51	10.35	7.43

*Lowercase letters indicate treatment groups that are significantly different according to Duncan's test at a 5% probability of error.

In the 2012/2013 agricultural year, the residual effect of nitrogen fertilization on the pasture at the time of corn cultivation was not verified. However, in 2013/2014, corn plants were taller when the pasture received 50 and 100 kg N ha^{-1} compared to the plots that did not receive nitrogen fertilizer. The availability of nitrogen applied to pasture during the winter for the corn crop in summer is related to the environmental conditions (Sandini et al., 2011); therefore, the 2012/2013 agricultural year may have suffered losses of nitrogen via leaching and/or volatilization, which may compromise the availability of this nutrient for corn.

There was a positive response in plant height in both crop years when corn seeds were inoculated with A. brasilense. Kappes et al. (2013) also found an increase in the height of corn plants when the seeds were inoculated with A. brasilense, a finding that has been attributed to the increased production of growth-promoting substances by the bacteria, such as indoleacetic acid (IAA). Steenhoudt and Vanderleyden (2000) reported a change in root morphology after inoculation with A. brasilense, which has been attributed to the production of plant growth-regulating substances, resulting in an increased root surface area via an increase in the number of lateral roots and root hairs. The resulting increase in the root surface area and subsequent increase in the uptake of water and nutrients are the main factors in increased plant growth.

During the 2012/2013 agricultural year, the effect of grazing management strategies and nitrogen fertilization of pasture in the FEH and SD of corn plants was not verified. However, in 2013/2014, the NG treatment plots had corn plants with higher FEH and SD than did the parcels where grazing was less intense (0.30 m). In the same year, a positive effect from nitrogen fertilizer applied on pasture was found in the FEH and SD of corn plants. Trogello et al. (2012) found that in an ICL system with black oat pastures managed at heights of 0.05, 0.15, and 0.30 m with herds, the initial plant height, first ear height, and productivity of corn grains were all adversely affected when the grazing height was 0.05 m.

Inoculation with *A. brasilense* did not increase the FEH or SD in corn plants during the 2012/2013 growing season but positively affected these measurements in the 2013/2014 agricultural year. According to Kappes et al. (2013), an increased stem diameter is ideal in corn crops because this feature is the best predictor of the percentage of lodging and breakage of plants. In addition, the greater the diameter is, the greater is the capacity of the plant to store photoassimilates that contribute to grain filling. These authors also reported an increase in FEH with the inoculation of *A. brasilense.*

No interaction was observed between treatments (grazing management × doses of N × inoculation) during the 2012/2013 agricultural year due to the following variables: ear length, ear diameter, number of rows, number of kernels per row, and grain productivity. However, there was an interaction between nitrogen levels × grazing management for the mass of one hundred kernels (Table 2). In the 2013/2014 agricultural year, there was a triple interaction (grazing management × doses of N × inoculation) for grain productivity (Table 3) and no interaction between the factors EL, ED, KN, NKR, and MOK (Table 2).

Table 2. Ear length (EL), ear diameter (ED), number of kernel rows (NR), number of kernels per row (NKR), kernel productivity (KP), and mass of one hundred kernels (MOK) of corn crop in a crop-livestock integration system during the 2012/2013 and 2013/2014 agricultural years.

Grazing management (Corn 2012/2013)		EL (m)	ED(m)	NR	NKR	KP (kg ha^{-1})
NG		0.1773	0.0488	15.75	36.2	7854.61
0.30 m		0.1778	0.0492	15.93	36.83	7741.14
0.20 m		0.1787	0.0490	15.83	36.2	7530.39
0.10 m		0.1779	0.0491	16.01	36.3	7693.61
CG		0.1760	0.0489	15.74	35.49	7340.7
Doses of	0 kg ha^{-1}	0.1775	0.0491	15.87	36.36	7542.04
N	50 kg ha^{-1}	0.1772	0.0488	15.85	35.81	7601.81
in pasture	100 kg ha^{-1}	0.1781	0.0490	15.84	36.5	7752.48
With *Azospirillum*		0.1848 a*	0.0495 a	15.91	38.04 a	7798.44 a
Without *Azospirillum*		0.1703 b	0.0484 b	15.8	34.4 b	7465.78 b
Average		0.1776	0.049	15.86	36.22	7632.11
CV (%)[1]		7.9	2.36	3.93	9.2	12.06
Doses of N in pasture		MOK (g) - Grazing management				
		NG	0.30 m	0.20 m	0.10 m	CG
0 kg ha^{-1}		35.78 aA	34.76 a AB	34.1 aB	34.8 aAB	33.74 bB**
50 kg ha^{-1}		35.08 aA	34.61 aA	34.1 aA	35.1 aA	34.37 bA
100 kg ha^{-1}		34.78 a AB	34.31 aB	34.6 a AB	34.4 aB	35.74 aA
Average		34.69		CV(%)	4.21	
Corn 2013/2014		EL (m)	ED (m)	NR	NKR	MOK (g)
NG		0.1513 a	0.0437 a	13.20 a	33.49 a	31.97 a
0.30 m		0.1436 b	0.0434 a	12.93 ab	31.96 b	31.21 b
0.20 m		0.1482 a	0.0436 a	12.85 b	32.25 ab	31.90 ab
0.10 m		0.1515 a	0.0429 a	12.99 ab	32.27 ab	32.12 a
CG		0.1487 a	0.0418 b	12.77 b	29.85 c	32.39 a
Doses of N in pasture		EL (m)	ED (m)	NR	NKR	MOK (g)
0 kg ha^{-1}		0.1497	0.0432	13.06	31.63	31.90
50 kg ha^{-1}		0.1468	0.0429	12.86	31.61	32.05
100 kg ha^{-1}		0.1495	0.0432	12.93	32.66	31.80
Inoculation (corn)		EL (m)	ED (m)	NR	NKR	MOK (g)
With *Azospirillum*		0.1558 a	0.0438 a	13.11 a	33.98 a	32.15 a
Without *Azospirillum*		0.1415 b	0.0423 b	12.79 b	29.95 b	31.69 b
Mean		0.1486	0.0431	12.95	31.97	31.92
CV (%)		611	5.05	4.46	8.77	4.69

* Different capital letters on the line and different lowercase letters in the column represent treatments that differ by 5% probability according to Duncan's test. CV (%)[1] = Percentual of variation coefficient.

The length and diameter of ears, number of kernels per row on each cob, and grain productivity were not affected by grazing management or levels of nitrogen applied to the pasture, but they responded positively to seed inoculation with *A. brasilense* in the 2012/2013 agricultural year. A longer ear length as a result of seed inoculation with *A. brasilense* was observed by Kappes et al. (2013), representing an increase of 3.7% compared to the treatment without inoculation. This finding was also verified by Cavallet, Pessoa, Helmich, Helmich, & Ost (2000), with an increased average ear length of 0.136 to 0.144 m.

In the 2012/2013 agricultural year, the mass of one hundred kernels varied depending on the levels of nitrogen that were applied to the pasture and grazing management. For the CG treatment, the MOK was higher with the application of 100 kg ha^{-1} N, making a case for the residual effect of nitrogen in this treatment. In contrast, in the 2013/2014 agricultural year, higher values for the MOK were found when the seeds were inoculated with *A. brasilense*, a finding that was also verified by Novakowiski et al. (2011) for the weight of one thousand kernels. Kappes et al. (2013) reported that grain mass is influenced by genotype, nutrient availability, and climatic conditions during the grain-filling stage.

The productivity of corn kernels increased by 333 kg ha^{-1} (4.5%) with the inoculation of *A. brasilense* in the 2012/2013 agricultural year. In agreement with this finding, several other studies reported an increase in corn productivity with the inoculation of *A. brasilense* (Cavallet et al., 2000; Hungria, Campo, Souza, & Pedrosa, 2010; Novakowiski et al., 2011). According to Bashan, Holguin, and De-Bashan (2004), there are indications that the positive effect of inoculation on gains in productivity is related not only to the capacity for biological nitrogen fixation but also to the bacteria's ability to produce substances that promote growth, such as auxin, gibberellins, and cytokinins. These growth-promoting hormones impact the metabolism and morphology of the plants, thereby improving the absorption of water and nutrients. Inoculation with *Azospirillum* spp. alters the morphology of the root system by increasing both the number of rootlets and the average diameter of lateral and adventitious roots, which in turn increases the absorptive surface area of plant roots, thereby allowing the exploitation of a higher volume of soil (Basi, Neumann, Marafon, Ueno, & Sandini, 2011). This effect may be beneficial to the grain during periods of low precipitation, as corn has high water requirements. Increasing the specific surface area of roots confers a greater capacity for the absorption of water and soil nutrients. In addition, the associative relationship between *A. brasiliense* and corn plants has a significant impact on plant metabolism (Walker et al., 2011).

The addition of phytohormones or changes in nitrogen availability can modify the total contents of secondary metabolites (e.g., alkaloids and total phenolic compounds) in plants. This result may be relevant because secondary metabolites not only can be exuded by the roots but are also exuded in greater quantities in inoculated plants (Raja, Gopal, & Govindarajan, 2006). In a study by Walker et al. (2011), the inoculation of corn seedlings changed the benzoxazinoid content in the plants, which plays an important role in plant defense. In addition, benzoxazinoid interferes with the function of plant hormones and has multiple effects on plant development, such as plant health and the composition of the rhizobacterial community.

Corn productivity in the 2012/2013 agricultural year was statistically similar when comparing grazing management strategies of black oat and ryegrass pasture, which is important because neither lighter grazing (0.30 m) nor more intense grazing (0.10 m) influenced the productivity of corn grown in succession. These results indicate that the use of sheep in crop areas during the winter period is beneficial and may serve as an alternate and surplus source of income for the producer in the winter period, thus optimizing the use of these areas throughout the year. Similar results were verified by Sandini et al. (2011), who found that corn productivity was not influenced by continuous grazing with sheep in black oat and ryegrass managed at a height of 0.14 m.

In the 2012/2013 agricultural year, nitrogen application on the pasture had no effect on corn productivity. Although not significantly different, when 100 kg ha^{-1} N was applied in the pasture, corn production increased by 210 kg ha^{-1} compared to areas that did not receive nitrogen. Considering only the gain in corn productivity, an application of 100 kg ha^{-1} N in the pasture would not be viable. However, considering the system as a whole, black oat and ryegrass respond to nitrogen application, resulting in increased pasture production, carrying capacity, and consequently, animal production.

In the 2013/2014 agricultural year, there was a triple interaction among the following variables: grazing management × doses of N × inoculation for productivity of corn kernels. Regarding grazing management strategies, the productivity of corn kernels was greater in the NG treatment and smaller in the CG group (Table 3). In the NG treatment, the quantity of residual dry matter of oat and ryegrass after grazing and at the time of sowing was 4,146.22 kg ha^{-1}, whereas the residual matter in the CG treatment was 1,182 kg ha^{-1}. When tilling, it is important to maintain an adequate amount of crop residues for soil protection, especially in drought situations, such as those that occurred in the 2013/2014 agricultural year. Assmann et al. (2003) found that when there is no added nitrogen, corn productivity increases linearly according to the amount of dry matter left as residue.

In the NG and CG treatments, inoculation with *A. brasilense* had a positive effect on corn productivity (Table 3). In the CG treatment group, productivity increased by 1,038, 1,573, and 962 kg ha^{-1} when 0, 50, and 100 kg N ha^{-1} was applied to the pasture, respectively, corresponding to increases of 38, 74, and 41% in productivity, respectively. In response to different grazing strategies, corn productivity was higher in the NG group and lower in the CG treatment; however, this decrease in productivity due to intense grazing can be partially offset by inoculation with *A. brasilense*. In this case, in the 2013/2014 agricultural year, the response of corn productivity to inoculation with *A. brasilense* was higher, which may be related to the use of the hybrid corn AS 1551 and to the drought conditions that occurred during this year.

Table 3. Corn kernel productivity (kg ha^{-1}) in a crop-livestock integration system during the 2013/2014 agricultural year.

	Corn kernel productivity (kg ha^{-1})					
		Grazing management				
	N in pasture	NG	0.30 m	0.20 m	0.10 m	CG
With *Azospirillum*	0 Kg N ha^{-1}	4367.72 aA	**β 2863.7 b C	3669.67 B*	3669.32 B	3752.74 aB
	50 Kg N ha^{-1}	4546.49 aA	β 3276.11 B	3531.63 B	3692.88 B	3685.33 aB
	100 Kg N ha^{-1}	4600.25 A	α 3914.48 B	3918.18 B	3889.49 B	3284.29 aC
Without *Azospirillum*	0 Kg N ha^{-1}	β 2980.52 b BC	3537.9 a AB	3634.75 A	3336.93 AB	α 2714.38 bC
	50 Kg N ha^{-1}	α 3971.33 b A	3202.75 BC	3052.38 C	3729.97 AB	β 2111.78 bD
	100 Kg N ha^{-1}	α 4206.02 A	3534.26 B	3396.75 B	3466.75 B	αβ 2322.23 bC

*Different capital letters on the line and different lowercase letters in the column treatments differ at 5% probability according to Duncan's test. **Greek letters displayed in the column represent differences between nitrogen levels within each level of inoculation and grazing management strategy.

According to Casanovas, Barassi, and Sueldo (2002), inoculation with *A. brasilense* increases the volume of roots and the water content of leaves, which can help mitigate water stress for corn plants. This effect can decrease the water supply for the crop by up to 75%, thus justifying the importance of encouraging drought-tolerant qualities in corn plants experiencing drought situations. On the other hand, Quadros et al. (2014) report that the climate and type of soil can lead to variations in the results of the inoculation and that every hybrid of corn responds differently to inoculation with *Azospirillum* spp. These authors report that the differences may be related to the relationship between the rhizosphere and bacteria, suggesting the need for further studies on corn hybrids that respond better to inoculation. Accordingly, Rahman, Mubassara, Hoque, & Khan (2006) found that most species of *Azospirillum* have an optimum growth temperature range of 35 to 37°C and prefer soils with a neutral or alkaline pH.

In NG treatments without *Azospirillum brasiliense* and a grazing management strategy of 0.30 m with *Azospirillum*, there was a residual effect of the nitrogen applied to the winter pasture on corn productivity. A likely explanation for this result is that in these treatments, due to the increased residual forage mass, nitrogen may have been immobilized on the straw of oat and ryegrass in larger amounts than in smaller residual masses, which was later made available for the successor crop.

Conclusion

Corn plants are taller when they are cultivated using black oat and ryegrass straw in the absence of grazing, which also favors crop productivity.

Under drought conditions, nitrogen applied to pasture favors the development of corn by increasing plant height, ear height, and stem diameter. In terms of corn productivity, this effect is pronounced in areas with higher residual forage masses.

Inoculation with the nitrogen-fixing bacterium *Azospirillum brasilense* had a positive effect on the characteristics of yield and productivity of corn, independent of the growing season and the hybrid used.

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