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Corn productivity in integrated crop-livestock system: Effect of different forage masses post-grazing

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Forage management in integrated crop-livestock system is a complex activity that increases profitability, when well performed, therefore consequently influencing future crop productivity. This study aimed to evaluate the agronomic performance of corn cultivation in the integrated crop-livestock system using the no-tillage system in different forage masses post-grazing. The experiment was conducted in the municipality of Mata, which is located in the state of Rio Grande do Sul, during the agricultural years of 2009/2010, 2010/2011, 2011/2012, 2012/2013 and 2013/2014, under no-till with corn in the summer and black oats plus ryegrass in the winter for grazing. The experimental design was made up of randomized blocks, using four heights of forage mass post-grazing: 0.10, 0.20, 0.30 m conventional grazing and without grazing. For the evaluation of the remaining dry mass of forage, a destructive cut was made at 5 cm from the soil at 28 days after the animals left. The evaluations of plant height, cob insertion height, number of grain rows, number of grains per cob, mass of one-thousand grains, and corn grain yield were performed. The average values of remaining forage mass were 1.52, 2.26, 2.44, 8.56 and 1.41 Mg ha^{-1} for the different grazing managements, in which corn productivity were 7.74, 8.82, 7.94, 9.22 and 7.70 Mg ha^{-1}. In absolute terms, the winter pasture management of 0.2 m high presented the best results in terms of corn grain productivity.

Key words: Soil coverage, forage, grazing height, income components, zero tillage.

INTRODUCTION

The production of food, bio-energy, fiber, wood and other goods are some of the many obstacles currently faced by researchers, technicians and farmers (Veiga et al., 2011). In order to meet modern-day demands, appropriate production systems with the least possible use of external inputs, environmental contamination and greenhouse gas emission must be adopted. No-till and integrated crop-livestock system are management alternatives with

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greater rationality of inputs employed that maintain and even increase production (Santos et al., 2008). These alternatives increase organic matter, which improves soil quality and aggregation (Conceição et al., 2005).

The integrated crop-livestock system is one of the most promising strategies for developing production systems that are more sustainable and have reduced input use because it assumes the continued use of agricultural land and improvement of soil quality over time (Rao et al., 2003). According to Veiga et al. (2011), this system integrates multiple biological, economic and social factors that interrelate and determine its sustainability. Additionally, ICL systems can improve nutrient cycling, reduce soil erosion, improve water use, interrupt pest and disease cycles as well as reduce investment risks through economic diversification (Allen et al., 2008).

Successful integration between systems depends on the employed stocking rate variable, its direct and indirect effects on the amount of forage as well as the nutrients that cycle in it (Carvalho et al., 2005). Overcrowding in grazing systems reduces the increment of the straw on the ground in direct consequence of managing smaller heights of forage plants, resulting in reduced productive potential of plants, problems with straw addition, compaction and soil erosion (Anghinoni et al., 2011). On the other hand, moderate grazing management grants plants the ability to grow and resprout, which is due to greater light interception compared to overcrowding (Souza et al., 2009).

In addition to pressure from grazing conferred by adjusting animal stocking and/or remaining height, the type of mulch can also modify the system, particularly nutrient cycling, decomposition rate and the addition of organic carbon to the soil. Forage legumes provide a greater increase of nitrogen on the successor crop, therefore ensuring cost reduction by means of nitrogen fertilization (Collier et al., 2006; Albuquerque et al., 2013). However, the use of grasses in the ICLS, in addition to allowing greater forage intake for grazing, can also contribute to nutrient cycling at a proportional rate or even higher depending on nitrogen management, carbon/nitrogen relation and lignin in the aerial part (Alvarenga et al., 2001; Doneda et al., 2012).

In small properties that adopt the integrated crop-livestock system, corn crops stand out as successors of the grazing period due to their numerous uses, such as in animal feed and green or conserved forage. Corn crop production reaches anywhere from 12000 to 13000 kg ha^{-1} of grains in commercial fields in Brazil. Additionally, in experimental conditions and by farmers who have adopted advanced technologies, it is even possible to obtain a production of approximately 15700 kg ha^{-1} (Mundstock and Silva, 2005). However, what is observed in practice are in fact considerably low and irregular yields, which average around 4795 kg ha^{-1} of grain (CONAB, 2016).

With the constant evolution of the agricultural sector since the introduction of No-till (NT), management rotation/crop succession and currently the integrated crop-livestock system (ICLS), the need for further studies in these areas that act in integrated fashion grows similarly. Therefore, the objective of this study is to evaluate the agronomic performance of corn crops in the integrated crop-livestock system in no-till farming in different forage masses post-grazing.

MATERIALS AND METHODS

The study was conducted on a farm during the agricultural years of 2009/10 to 2013/14, at the Central Depression of Rio Grande do Sul (103 m height, latitude 29°07 ' 34 "S and longitude 54°27 ' 29"). Climate is 'Cfa' type in the Köppen classification (Peel et al., 2007), with rainfall and annual average temperatures ranging between 1,558 and 1,762 mm and 17.1 and 17.9°C, respectively. The soil of the experimental area is classified as Rhodic Paleudalf (Embrapa, 2013) with physical-chemical features obtained through sampling in the 0.2 m layer for the implementation of the experiment. Sampling revealed the following values: pH 5.5 water; organic matter of 5,0 g kg^{-1}; P-Mehlich-1 of 49,4 mg dm^{-3}; 155,4 mg dm^{-3} of K; 1,31 $cmol_c$ dm^{-3} of Ca^{+2}; 0,37 $cmol_c$ dm^{-3} of Mg^{+2}; and $CTC_{pH\ 7,0}$ of 8,23 $cmol_c$ dm^{-3}, sand, clay and silt of 557, 195 and 248 g kg^{-1}, respectively (Tedesco et al., 1995).

The experimental design comprised of randomized blocks with three replications and five treatments, totaling 15 experimental units (EU) with dimension 14 m × 15 m. Treatments consisted of four heights of forage mass post-grazing: forage mass height of 0.10 m (M-10); 0.20 m (M-20) and 0.30 m (M-30) continuous grazing (CG), with an area of 500 m^2 and intensity of free grazing for the animals and control treatment without grazing (TWG).

The experiment was conducted in mid-April of 2009, in an area of 3000 m^2 and in a system integrating grain production with livestock production. The pasture component was implanted in April for the respective agricultural years and made up of a consortium of black oats (*Avena strigosa* Schreb.) and ryegrass (*Lolium multiflorum* Lam.) in the proportion of 70 kg ha^{-1}, 25 kg ha^{-1} of viable seeds, respectively. These seeds were sown in total area coverage and the corn crop of the previous crop was then mowed on the seeds, avoiding the sorting.

The mineral fertilizer used in the corn crops and forage was based on the recommendation for the respective crops according to the manual of liming and fertilization (CQFS-RS/SC, 2004), and obtained through soil sampling prior to the deployment of each crop. The nitrogen fertilization cover for the corn crops was carried out at two different times, comprising of the phenological stages V4 and V8 (fourth and eighth leaves), and for grazing, this fertilization was conducted in three moments and applied in the phenological stage of oat crop tillering and after each grazing (Weismann, 2007).

For the characterization of the vertical structure of the pasture, the monitoring of the height was carried out through the ruler method (sward stick), which was adapted from Barthram (1985), in which an overhead projector marker moves through a graduated ruler until it touched the leaf surface canopy. This monitoring was carried out before the entry of the animals, during grazing and after the departure of the animals to ensure the desired height was maintained. Grazing were carried out around 70, 100 and 130 days after the emergence of pastures for the different heights of forage mass post-grazing of the respective five years. The period for the entry of the animals into the first pasture occurred when the forage reached an average height of 0.40 m and the remaining grazing were performed at intervals of 28 days, using lactating cows of the Jersey breed with 2.4 animal units per EU.

Measurement of the remaining biomass of forage was conducted 28 days after the last grazing, collecting three samples through destructive cuts of pasture in random places and delimited by a metal square of 0.25 m^2, which was obtained by cutting with scissors and adjacent to the ground. Afterwards, the remaining biomass of forage were dried in an oven with forced air circulation of 65°C for 72 h and then weighed on a precision balance.

Subsequently, desiccation of the pasture was performed using glyphosate herbicide at the dosage of 3 L ha^{-1} of commercial product, respecting an interval of 15 days to perform sowing in no-till system. Hybrid sowing occurred on 11/17/2009, 12/14/2010, 12/10/2011, 11/25/2012 and 12/13/2013 for the respective agricultural years, and had 0.60 m spacing between rows. The emergence of the seedlings occurred five days after sowing, with a final density of 70,000 plants ha^{-1}.

Grain harvest was performed manually in the phenological stage R6 (physiological maturity) in an area of 2.8 m^2 with three samples in each sub-plot, which occurred from mid-March to the first fortnight of April of the respective agricultural years of when the evaluations were performed. The evaluations performed were:

Cob insertion height, number of grain rows, number of grains per cob, mass of one-thousand grains and grain productivity corrected for 13% humidity.

The results were submitted to analysis of variance using the Tukey test at 5% probability of error. The statistical software GENES (Cruz, 2013) was used.

RESULTS AND DISCUSSION

Results of the remaining dry forage mass of the winter period can be seen in Table 1, on the grounds that the different heights of forage mass post-grazing became the substrate for sowing the corn crop. In the five-year evaluation of the RDFM of winter, there were differences between post-grazing heights.

In this evaluation period, the average amount of mulching that remained until the time of corn sowing ranged, respectively, from 1410 to 8560 kg ha^{-1} for conventional grazing and without grazing, and possessing an average 3240 kg ha^{-1} of mulching that was on the ground at the time of corn sowing (Table 1). Different grazing pressures allowed the development of quantities of plant residue on the soil surface, ranging from 1850 to 5400 kg ha^{-1}, from the largest to smallest grazing pressure, respectively, and being 6050 kg ha^{-1} in the area without grazing (Flores et al., 2007) (Table 1).

In the integrated crop-livestock system, the themed research is tied to the establishment of the ideal amount of straw in order to ensure adequate soil coverage for successor crops, which are sown in periods that frequently have dry spells. Additionally, straw coverage mitigates the impact of mechanical pressure of trampling (Braida et al., 2006). One of the requirements for the success of the no-tillage system (NTS) is the favorable formation of straw coverage on the soil surface (Pariz et al., 2011). The success of theno-tillage system also depends on the annual addition of straw coverage to cover the ground and must not be less than 8000 kg ha^{-1} (Lovato et al., 2004; Nicoloso et al., 2006). Depending on the crop that will be used in succession and the remnant of winter forage straw, this goal can be achieved. However, to maintain and/or increase the soil organic carbon content in the NTS, the amount of stover must be increased from 10000 to 12000 kg ha^{-1} per year (Bayer, 2001).

Nevertheless, the remaining straw forage (Table 1) did not affect the results of the straw found in this study, reinforcing the importance of crop rotation, especially when leaving favorable amounts of straw at the end of the grazing cycle. Regarding the productivity of corn grains in the agricultural year of 2009/10, it was possible to observe a difference between the different masses of forage post-grazing (Table 1). The most grazed treatments (10-M and CG) resulted in lower grain productivity when compared to the other treatments, which did not differ statistically between themselves.

Grain yields varied from 9600 to 11600 kg ha^{-1}, respectively, for CG and 30-M, with an average yield of 10640 kg ha^{-1} (Table 1). Results of smaller grain yields were repeated in the agricultural year of 2010/11, for CG and 10-M, and 5300 5300 kg ha^{-1}, respectively, and the average productivity of the treatments were 6260 kg ha^{-1} (Table 1). In order to mitigate the loss of productivity in periods of water deficit during sowing, soil mulching is essential, as it helps maintain hydrothermal features (Resende et al., 2005). This is confirmed in the agricultural years 2010/11 and 2011/12, since these years suffered water deficits, where the difference of income ranged from 1900 and 1400 kg ha^{-1} for CG and NG for the respective agricultural years evaluated (Table 1).

Studies that link different grazing intensities found that the higher the grazing intensity, the lower the yield of corn grain, with a difference of 1300 kg ha^{-1} between the most grazed versus the least grazed treatment, of which was associated to greater soil compaction in areas of greater grazing intensity (Journal et al., 2006).

For the agricultural years 2012/13 and 2013/14, climatic conditions favored better performance for different heights of forage mass post-grazing and without grazing, with average yields of 8300 and 9980 kg ha^{-1} for the respective agricultural years (Table 1). Furthermore, it is possible to observe that the corn grain yield of the CG was equal to other treatments that maintained a greater supply of straw at the end of the grazing cycle (Table 1).

In the average of the five agricultural years evaluated, corn grain yield ranged from 7700 to 9220 kg ha^{-1} for CG and NG, respectively, with a difference of 1520 kg $ha-^{1}$ for the area with the lowest soil coverage areas without grazing (Table 2). These results corroborate with the literature, such as by Nicoloso et al. (2006) and Trogello et al. (2012), who report differences in 1300 and 2000 kg

Table 1. Average remaining dry forage mass (RDFM) and grain productivity (GP) grown in no-tillage system in integrated crop-livestock system, in five agricultural years and in different heights of forage mass post-grazing.

Height of forage mass post-grazing	Agricultural year					
	2009/10	2010/11	2011/12	2012/13	2013/14	Average
RDFM (kg ha^{-1})						
10-M	1100^{c}	2200^{cd}	1900^{b}	1200^{c}	1200^{d}	1520^{b}
20-M	2400^{b}	2900^{bc}	2100^{b}	1900^{b}	2000^{c}	2260^{b}
30-M	2200^{b}	3600^{b}	2000^{b}	2100^{b}	2300^{b}	2440^{b}
NG	9200^{a}	8100^{a}	10100^{a}	7300^{a}	8100^{a}	8560^{a}
CG	550^{c}	2000^{d}	2100^{b}	1200^{c}	1200^{d}	1410^{b}
CV (%)	8.13	7.52	3.92	5.680	2.95	-
GP (kg ha^{-1})						
10-M	9920^{b}	5510^{c}	6130^{bc}	7860^{cd}	9160^{b}	7710^{b}
20-M	10860^{a}	6650^{ab}	6240^{b}	8750^{ab}	11470^{a}	8780^{ab}
30-M	11600^{a}	6590^{b}	6110^{bc}	7440^{d}	8130^{b}	7950^{ab}
NG	11150^{a}	7210^{a}	7090^{a}	9190^{a}	11410^{a}	9210^{a}
CG	9630^{b}	5200^{c}	5730^{c}	8240^{bc}	9730^{ab}	7710^{b}
Average	10634	6216	6264	8301	9983	-
CV (%)	2.58	3.56	2.49	2.4	6.52	-

*Averages followed by the same letter in the same column do not differ by the Tukey test at 5% probability. CV: Coefficient of variation.

ha^{-1}, respectively, from the lowest to the highest grazing intensity. Regarding the productivity of corn grains conducted in five years, they indicate that among the grazed areas, the height of forage mass post-graze of 20-M was the one that presented the best average yield in this evaluated period, with 8820 kg ha^{-1} (Table 2).

The average height of the cob was influenced by different forage masses after grazing (Table 2). Continuous grazing provided the lowest CIH, although it differed statistically from M-10 and NG, which did not differ from the other post-grazing forage masses (Table 2). The evaluation of this variable is very important since it is related to lodging, which leaves the taller plants more susceptible. Notwithstanding, the cob insertion height is a very important parameter in mechanized harvesting because it has significant effect on total grain loss. However, Junior et al. (1997) highlight that the CIH should be above 1.0 m in mechanized harvesting, and the CIH below this height, especially the CG average (Table 2). This cob insertion height is not influenced by the use of green manure in soil coverage (Santos et al., 2010).

For the number of grain rows, there were statistical differences in the agricultural years 2010/2011 and 2012/2013, and in the remaining agricultural years this variable was not influenced by the different masses of post-grazing forage. In the five evaluated agricultural years, it is possible to observe that in the average NGR there was an interaction between the different post-grazing forage masses, resulting in CG having lower NGR, and not being different than the M-10 of which did not differ from the other treatments (Table 2). For Valle et al. (2013), the NGR is more influenced by genetic character, population, plant population used and doses of nitrogen (Carmo et al., 2012) than predecessor cover crops (Albuquerque et al., 2013).

The different post-grazing forage masses influenced the number of grains per cob in the agricultural years 2010/2011 and 2012/2013, and in the remaining crop years this variable was not influenced by the different treatments (Table 2). The average of the variable NGC of the five years evaluated did not differ between M-10 and CG, of which did not differ from the NG and M-30 that were statistically equal to M-20 (Table 2). For Bravin and Oliveira (2014), the NGC is an important variable because it is directly related to corn productivity. When there are no limitations in the system, the NGC is greater when there is adequate availability of nitrogen for the plants in the soil (Soratto et al., 2011), which results in major gains of production.

The thousand-grain weight, which is an important component of productivity, presented significant differences in three of the five agricultural years evaluated (Table 2). In the average of the different post-grazing forage masses in five years, there were no statistical differences between the treatments. This is the production component less affected by changes in management and fertilization practices, with a feature

Table 2. Cob insertion height (CIH), number of grain rows (NGR), number of grains per cob (NGC), mass of a thousand grains of corn (MTG), grown in no-tillage system in integrated crop-livestock system in five agricultural years, in different heights of forage mass post-grazing.

Agricultural year	Height of forage mass post-grazing					CV (%)
	M-10	M-20	M-30	NG	CG	
CIH (m)						
2009/2010	0.89^{ab}*	0.90^{a}	0.82^{bc}	0.78^{c}	0.62^{d}	7.59
2010/2011	0.98^{c}	1.07^{ab}	1.10^{a}	1.13^{a}	1.03^{c}	4.2
2011/2012	0.98^{a}	0.90^{ab}	0.96^{ab}	0.94^{ab}	0.82^{c}	5.29
2012/2013	1.0^{b}	1.03^{ab}	1.03^{ab}	1.04^{a}	1.01^{ab}	2.64
2013/2014	0.93^{b}	0.98^{a}	0.99^{a}	0.97^{ab}	0.85^{c}	4.21
Average	0.96^{ab}	0.98^{a}	0.98^{a}	0.97^{ab}	0.87^{b}	-
NGR						
2009/2010	15^{ns}	15	15	15	14	6.74
2010/2011	13^{b}	14^{ab}	14^{ab}	15^{a}	13^{b}	6.07
2011/2012	14 ns	15	14	15	13	9.98
2012/2013	13^{ab}	13^{ab}	14^{a}	13^{ab}	12^{b}	7.77
2013/2014	12 ns	13	13	13	12	7.1
Average	13.4^{ab}	14.0^{a}	14.0^{a}	14.2^{a}	12.8^{b}	-
NGC						
2009/2010	508 n^{s}	541	496	515	506	9.43
2010/2011	292^{b}	372^{a}	326^{ab}	352^{a}	292^{b}	8.32
2011/2012	479 n^{s}	507	517	507	479	5.76
2012/2013	285^{b}	382^{a}	341^{ab}	367^{a}	285^{b}	13.13
2013/2014	495 n^{s}	529	496	503	528	17.48
Average	411.8^{b}	466.2^{a}	435.2^{ab}	448.8^{ab}	418.0^{b}	-
MTG (g)						
2009/2010	288^{b}	289^{b}	311^{a}	273^{b}	272^{b}	2.34
2010/2011	384^{ab}	380^{b}	354^{c}	402^{a}	382^{b}	1.85
2011/2012	344 n^{s}	342	345	340	342	2.42
2012/2013	325^{a}	304^{b}	320^{ab}	321^{ab}	329^{a}	2.1
2013/2014	266 n^{s}	284	282	245	293	10.87
Average	321.4^{ns}	319.8	322.4	316.2	323.6	-

*Averages followed by the same letter on the same line do not differ by the Tukey test at 5% probability. CV%: percentage variation coefficient. NS = Not significant.

more influenced by the hybrid, nutrition and climatic conditions (Ohland et al., 2005).

Conclusion

Superior productivity of corn in integrated crop-livestock system was found for 0.2 and 0.3 m high pasture forage management. The ungrazed system provided the most remaining forage mass for sowing corn, and consequently increased crop productivity. The treatments M-20 and M-30 were ideal for the realization of direct seeding in grazed areas.

CONFLICT OF INTERESTS

The authors declare no conflict of interest in the publication of this manuscript.

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