UNIVERSIDADE FEDERAL DE LAVRAS

ITALO BRAZ GONCALVES DE LIMA

GRAZING SNAPLAGE RESIDUE AS A ROUGHAGE SOURCE FOR FINISHING BEEF CATTLE: EFFECTS ON BEEF PRODUCTION, SOIL PROPERTY, AND SUBSEQUENT CROP YIELD

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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-graduação em Zootecnia, área de concentração em Produção e Nutrição de Ruminantes, para obtenção do título de Doutor

Prof. Dr. Daniel Rume Casagrande

Orientador

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PASTEJO DO RESIDUO DE SNAPLAGE COMO UMA FONTE DE FORRAGEM PARA TERMINACAO DO GADO DE CORTE: EFEITOS SOBRE A PRODUÇÃO ANIMAL, PROPRIEDADES DO SOLO E RENDIMENTO DA LAVOURA SUBSEQUENTE

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“If you got a chance, take it, take it while you got a chance
If you got a dream, chase it, 'cause a dream won't chase you back”
(Cody Johnson –‘‘Til You Can't’)

GENERAL ABSTRACT

The integrated crop-livestock system (ICLS) allows for more profitability with efficient land use. With the increasing use of snaplage in Brazil, grazing by animals of the abundant post-harvest residue can be an excellent option for use in an ICLS. This study evaluates the effects of grazing on residue characteristics, soil characteristics, animal performance and behavior, and subsequent crop yield in the ICLS. Immediately after the corn harvest, the area was divided into twenty-four paddocks, and treatments were randomly assigned. The treatments were two stocking rates (SR): 1) Low Stocking Rate (LS; 3.5 AU/ha), and 2) High Stocking Rate (HS; 7.0 AU/ha) and Ungrazed Control (CT). The treatments were obtained by modifying the size of the paddocks. Crossbred heifers (n = 48, initial body weight = 275 ± 23 kg) were randomly distributed in 16 paddocks (3 per paddock). Data were analyzed using the PROC MIXED procedure of SAS. Means were estimated using LSMEANS and compared using the Tukey test. For soil physical and chemical characteristics and subsequent crop yield, pre-planned contrasts were CT versus HS+LS and HS versus LS with a significance of $P \leq 0.05$. Multivariate analysis was performed using the principal component analysis method. The initial residue mass was similar for all treatments (9,600 kg DM/ha). There was less final mass for HS ($P < 0.01$) than for CT. There was no SR x time effect ($P = 0.88$) on total mass. There was less total mass for HS ($P < 0.01$) than LS and total mass decreased over time ($P < 0.01$). There was also less total pre-plant mass for HS and LS ($P < 0.01$) than for CT. No effect of grazing or SR ($P \geq 0.22$) was detected for penetration resistance. Total nitrogen returning was increased by grazing (82% compared to ungrazed; $P < 0.01$). The macronutrients phosphorus (P) and potassium (K) were also increased by grazing (28 and 42%, respectively). There was a time effect ($P < 0.01$) for grazing, idleness, and bunk visit. There was no difference between HS and LS for residue intake ($P = 0.34$; 0.434 vs. 0.478 kg/day, respectively), concentrate intake ($P = 0.84$; 7.72 vs. 7.78 kg/day, respectively), and average daily gain (ADG; $P = 0.94$; 0.952 vs. 0.956 kg/day, respectively), The HS treatment increased ($P < 0.01$) gain per area (618 vs. 309 kg/ha) compared to LS. Grazing increased subsequent crop yield (15% compared to the ungrazed; $P \leq 0.04$). In conclusion, residue grazing allowed the addition of beef production between two corn crops and did not affect the performance of finishing heifers, but the higher stocking rate increased the gain per land area. Grazing snaplage residue positively affected the yield of the subsequent corn crop.

Keywords: Beef cattle. Integrated crop-livestock system. Snaplage residue. Corn production

RESUMO GERAL

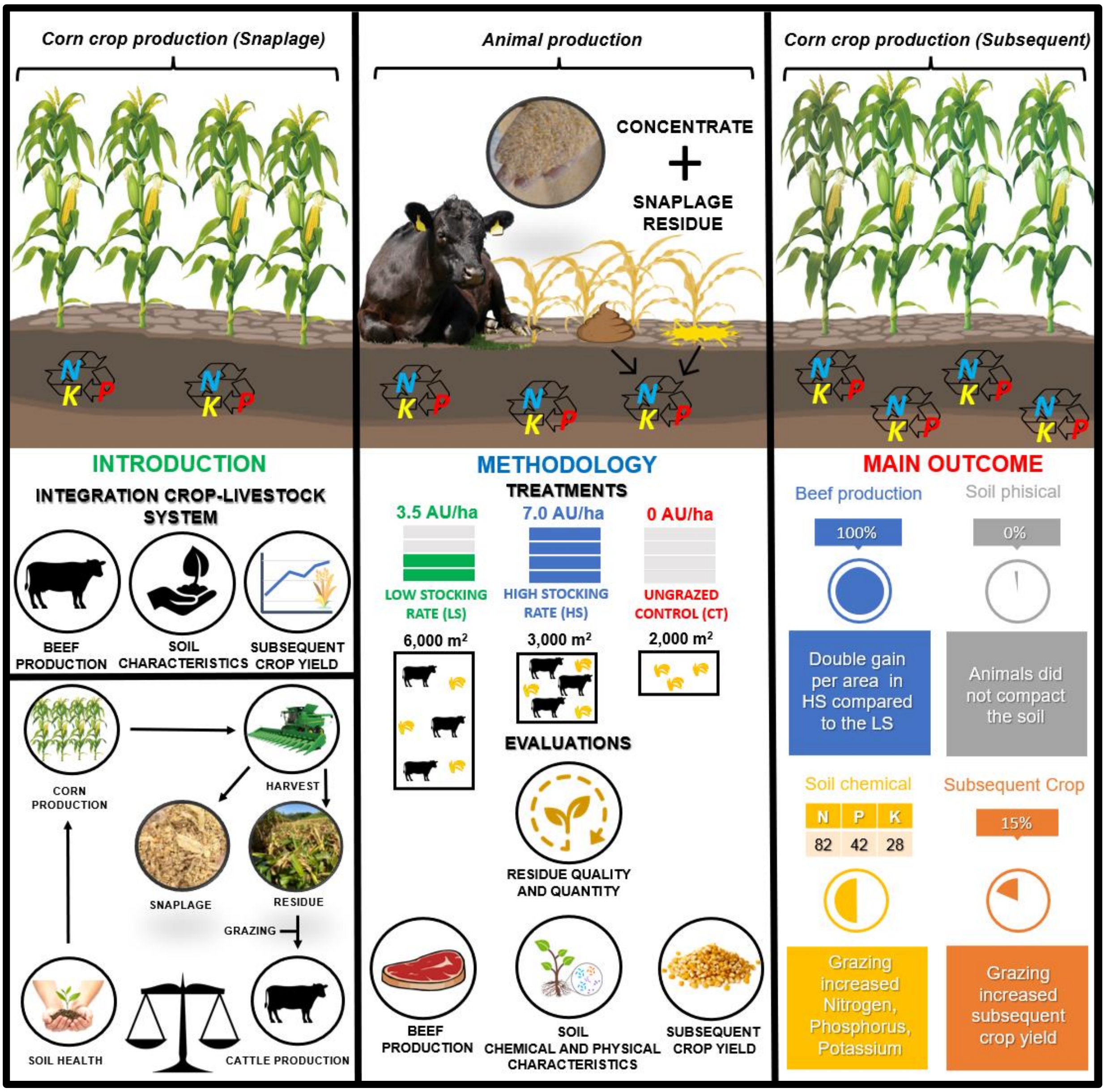
O sistema de integração lavoura pecuária (ILPs) permite uma maior rentabilidade com uso eficiente da terra. Com o uso crescente do snaplage no Brasil, o pastejo por animais dos abundantes resíduos pós-colheita pode ser uma excelente opção para uso em um ILPs. Este estudo avalia os efeitos do pastoreio sobre as características dos resíduos, características do solo, desempenho e comportamento dos animais, e o subsequente rendimento da cultura no ILPs. Imediatamente após a colheita do milho, a área foi dividida em vinte e quatro piquetes, e os tratamentos foram atribuídos aleatoriamente. Os tratamentos foram duas taxas de lotação (SR): 1) Baixa Taxa de Lotação (LS; 3,5 UA/ha), e 2) Alta Taxa de Lotação (HS; 7,0 UA/ha) e Controle (CT). Os tratamentos foram obtidos através da modificação do tamanho dos piquetes. As novilhas cruzadas (n = 48, peso inicial do corpo = 275 ± 23 kg) foram distribuídas aleatoriamente em 16 paddocks (3 por piquete). Os dados foram analisados utilizando o procedimento PROC MIXED da SAS. As medias foram estimados usando LSMEANS e comparados usando o teste Tukey. Para as características físicas e químicas do solo e a produção da lavoura subsequente, os contrastes pré-planejados foram CT versus HS+LS e HS versus LS com significância de $P \leq 0,05$. A análise multivariada foi realizada utilizando o método de análise de componentes principais. A massa de resíduo inicial foi semelhante para todos os tratamentos (9.600 kg DM/ha). Havia menos massa de resíduo final para HS ($P < 0,01$) do que para CT. Não houve efeito de SR x tempo ($P = 0,88$) sobre a massa total. Havia menos massa total para HS ($P < 0,01$) do que para LS e a massa total diminuiu ao longo do tempo ($P < 0,01$). Havia menos massa total pré-plantio para HS e LS ($P < 0,01$) do que para CT. Nenhum efeito de pastejo ou SR ($P \geq 0,22$) foi detectado para resistência à penetração. O balanço de nitrogênio aumentou com o pastejo (82% comparado ao não pastejado; $P < 0,01$). Os macronutrientes fósforo (P) e potássio (K) também foram aumentados pelo pastejo (28 e 42%, respectivamente). Houve um efeito de tempo ($P < 0,01$) para o pastoreio, ociosidade e visita ao cocho. Não houve diferença entre HS e LS para consumo de resíduos ($P = 0,34$; 0,434 vs. 0,478 kg/dia, respectivamente), consumo de concentrado ($P = 0,84$; 7,72 vs. 7,78 kg/dia, respectivamente), e ganho médio diário (GMD; $P = 0,94$; 0,952 vs. 0,956 kg/dia, respectivamente), O tratamento HS aumentou ($P < 0,01$) ganho por área (618 vs. 309 kg/ha) em comparação com o LS. O pastejo aumentou o produção da lavoura subsequente (15% em comparação com o não pastoreado; $P \leq 0,04$). Em conclusão, o pastejo de resíduo permitiu a adição uma produção animal entre duas lavouras de milho e não afetou o desempenho das novilhas em terminação. Entretanto, a maior taxa de lotação aumentou o ganho por área de terra. O pastejo do resíduo afetou positivamente o rendimento da safra de milho subsequente.

Palavras-chave: Bovinos de corte. Sistema de integração lavoura pecuária. Resíduos de snaplage. Produção de milho.

ABSTRACT INTERPRETATIVE

Integrated crop-livestock system (ICLS) is a management practice that uses the same land area to produce one crop, followed by livestock production, and usually followed by similar crops or not. This system aims to take advantage of the direct and indirect benefits brought by each component to the other in a complementary mutualistic relationship. The main objective of producing a corn crop is to harvest grain (for human or animal food) or to produce silage (exclusively for animal feed). Silage is a process of food conservation through anaerobic fermentation, and there are several types of silage. The choice of the most appropriate type of silage can vary with the objective of the farm, the location, and the time of the year. Snaplage is silage produced using only the corn ear (cob, husk, and grains). However, this process leaves a large quantity of residue consisting of leaf and stem behind, which remains in the area as a ground cover. A different strategy for using this residue would be grazing by animals. However, there are still concerns among producers and researchers if animal grazing would affect the soil positively or negatively, and consequently, the subsequent crop yield. Another question to be evaluated is whether an increase in stocking rate could compromise the performance of the animals. The experimental area was divided into paddocks with high stocking rates (more animals per unit of area), low stocking rates (fewer animals per unit of area), and ungrazed paddocks (no animals). This research demonstrated that the amount of residue decreased over time in all the paddocks, especially the more digestible material such as leaf and sheath. When planting the next crop, the grazed paddocks had less residue than the ungrazed ones. The disappearance is a result of grazing and trampling by the animals and weathering. Grazing by the animals did not compact the soil, one of the indicators of physical characteristics, at either of the stocking rates evaluated. Grazing by animals increased the amount of soil nutrients, nitrogen, phosphorus, and potassium. In both stocking rates, the animals consumed similar amount of residue and feed daily and consequently had similar performance. However, at the higher stocking rate, production per unit of area was double compared to the lower stocking rate. The subsequent crop yield increased when the paddocks were grazed compared to ungrazed ones. Thus, we concluded that it is possible to use the residue for animal finishing in an ICLS, adding cattle production between two crop rotations without affecting the soil's physical characteristics and the animal's performance. Putting more animals in the area allows for doubling the productivity per unit area, and adding animals positively affects the subsequent crop yield.

GRAPHICAL ABSTRACT



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ABBREVIATIONS AND ACRONYMS

ADG	Average Daily Gain
ADG	Average Daily Gain
AN	Animal Nitrogen
apNDF	Neutral Detergent Fiber Corrected to Ash and Protein
BD	Bulk Density
CP	Crude Protein
CP/DOM	Crude Protein/Digestible Organic Matter Ratio
CT	Ungrazed Control
DM	Dry Matter
DMI	Dry Matter Intake
DOM	Digestible Organic Matter
DOMI	Digestible Organic Matter Intake
EE	Ether Extract
EM	Ear Mass
FNE	Feces Nitrogen Excretion
GMD	Geometric Mean Diameter
HS	High Stocking Rate
ICLS	Integrated Crop-Livestock System
iNDF	Indigestible Neutral Detergent Fiber
LS	Low Stocking Rate
MACROp	Macroporosity
MVC	Mass of Vegetative Components;
MWD	Mean Weight Diameter
NDF	Neutral Detergent Fiber
OM	Organic Matter
PR	Penetration Resistance
PRfc	Penetration Resistance At Field Capacity
RM	Residual Mass
RN	Residue Nitrogen
SD	Soil Density
SEM	Standard Error of Means
SR	Stocking Rates
TIP	Termination Intensive in Pasture
TIR	Termination Intensive in Residue
TNR	Total Nitrogen Returning
TYdm	Total Yield Dry Matter
UNE	Urinary Nitrogen Excretion
WMD	Weighted Mean Diameter

cm.	Centimeter
d.	Day
Fig.	Figure
h.	Hour
ha.	Hectare
K.	Potassium
Kg.	Kilogram
m.	Meters
min.	Minutes
mm.	Millimeter
N.	Nitrogen
P.	Phosphorus
SB.	Sum of bases,
T.	Cation exchange capacity
Ton.	Tons
V.	Soil base saturation;

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OVERALL INTRODUCTION

Developing ear harvesting platforms and self-propelled forage harvesters favored the increasing use of snaplage, a type of silage from the 1950s, in Brazilian beef production units. Snaplage is composed of the ear (cob and grain), husk, and (Ferraretto et al., 2018). in this type of silage, an abundant residue is left, about 50% of the crop, composed of stem and leaf, and usually, remains in the soil being naturally degraded, favoring the cycling of nutrients, providing organic matter for the soil and ground cover for the next crop. However, this material has great potential to be grazed by cattle taking advantage of the ability of ruminants to consume low nutritional quality material such as residues and co-products that are not part of the human diet (Russelle et al., 2007a), and turn them into high-quality foods such as meat and milk.

Corn residue grazing is a widely used management strategy in the Midwestern United States (Lehman et al., 2021; Russelle et al., 2007a) that occurs at different times of the year depending on weather, resource availability, and farm location (Ulmer et al., 2019). The grazing of residue leads to the disappearance of the material by intake or trampling. In addition, weathering is one of the main factors causing residue disappearance (Lehman et al., 2021; Stalker et al., 2015). The disappearance of more digestible components of the corn residue, either by weathering or grazing selectivity, will result in a change in the nutritive value of the diet (Fernandez-Rivera and Klopfenstein, 1989a; Lamm and Ward, 1981; Lehman et al., 2021; Stalker et al., 2015) since the most digestible components are the first to disappear, leading to a reduction in animal performance (Russell et al., 1993). Thus, the animals must be supplemented mainly with protein sources

Supplementation in the termination intensive in residue system (TIR) based on feeding large amounts of feed concentrate with snaplage residue as a source of roughage to maintain rumen health since animals on high-concentrate diets is predisposed to metabolic disturbances caused by acidosis. A system similar to that used in Brazil, well known in Brazil as intensive pasture termination (TIP), is based on providing similar levels of concentrate as those adopted in the feedlots to animals kept on pasture (Moretti, 2015). However, when the TIP is used in the rainy season, it is possible to have a constant quantity and quality of forage without affecting animal performance. In TIR, the dynamics are different from that of TIP because there is no increasing forage due to losses in quantity and quality due to the aforementioned factors, leading to a decrease in animal performance due to metabolic problems that mainly affect the intake and, consequently, animal performance. Thus, it is necessary to have a correct stocking rate that allows the offer of residue in an amount that does not compromise the animal performance and, at the same time, allows the use of the residue efficiently and without damaging the soil, making it possible to include meat production between two corn crops that fit perfectly in an integrated crop-livestock integration system (ICLS).

Integrated crop-livestock system (ICLS) is a production strategy growing in Brazil in recent years. It aims to use different production systems to take advantage of soil, plant, and animal characteristics in a complementary way within the same area. This system can be separated by a spatial-temporal difference in succession or rotation, promoting benefits for all activities (Russelle et al., 2007b; Sulc & Franzluebbers, 2014). However, understanding the effects of grazing in this system is critical, especially the impact on subsequent crop production, since previous research has shown that livestock grazing can negatively affect soil physical properties (Betteridge et al., 1999; Clark et al., 2004; Krenzer et al., 1989; Mapfumo et al., 2011). On the other hand, grazing with residues has been shown to increase soil nutrient availability in several studies (Agostini et al., 2012; Drewnoski et al., 2016; Maughan et al., 2009; Tracy and Zhang, 2008) , although many believe that grazing will increase the removal of residues and hence the availability of soil nutrients returning via cycling, The N, P K, and some of the C consumed by the animals when they are supplemented, are cycled through their excreta becoming an additional source of nutrients to the soil (Rakkar and Blanco-Canqui, 2018a).

These conflicting results of the impact of residue grazing on the subsequent crop can be influenced by different soil types, climates, and crop management (Wilhelm et al., 2004). Therefore, research is needed to understand the dynamics of TIR by evaluating different stocking rates to understand how reducing the quality and quantity of residue affects animal productivity and how this system fits into an ICLS system to understand the effect of residue grazing on soil chemical and physical characteristics and its impact on subsequent crop yield.

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LITERATURE REVIEW

Corn production has an expansive number worldwide due to the importance of this cereal for food. In the United States, the world's largest producer, the 2021 production data indicated that an area of about 34 million hectares of corn will be harvested with yields of 11.9 t/ha (USDA-NASS, 2022). It is estimated that 404 million tons of residue will be produced due to the harvest of all this production. The amount of residue produced per hectare is estimated using corn yield values and stover mass to grain mass ratio of 1:1 (Graham et al., 2007) considering the harvest index (HI) of 0.5 as reported by Gupta et al. (1979). In Brazil, the world's third-largest producer, the 2021/2022 crop is expected to produce 125.5 million tons of corn, with approximately 19.8 million hectares planted (CONAB, 2022). According to Daniel et al., (2019), approximately 20% of this area will be used to produce corn silage.

Whole-plant corn silage production focuses on utilizing the complete plant, consequently leaving less residue behind when compared to harvesting corn for grain. However, new technologies in corn silage production, including ear harvesting platforms and self-propelled forage harvesters, are emerging. This technology has allowed the use of snaplage, a reemerging type of silage whose preliminary studies date back to the 1950s, to increase considerably in Brazilian feedlots. It is currently adopted in about 12% of the finishing diets of Brazilian cattle as a method of grain processing (Bernardes and Castro, 2019). Snaplage usually contains the ear (cob and grain), husk, and shank (Ferraretto et al., 2018). Like the production of corn grain, snaplage leaves a considerable amount of residue in the field, around 50%, composed of stalks and leaves that, when naturally degraded, favor the cycling of nutrients, providing organic matter for the soil and ground cover for direct planting of the next crop. The abundant residue in this system can be used as a roughage source in ruminant diets. The use of corn residue for grazing is a widely used strategy in the Midwestern United States (Lehman et al., 2021; Russelle et al., 2007b), providing producers with an economical feed source and helping to reduce feed costs during the winter (Klopfenstein et al., 1987; Lehman et al., 2021).

Ruminants can consume material of low nutritional quality as residues and co-products that are not part of the human diet (Russelle et al., 2007b) and transform them into high-quality foods such as meat and milk. Corn residue is a forage with relatively low nutritional quality since it can only be used after harvest. At this stage, the plants have already reached physiological maturity, so their nutritional value is low, with low protein content and digestible energy (Klopfenstein et al., 1987; Oltjen and Beckett, 1996). However, among the plant parts that constitute the residue, there are different levels of digestibility and nutritive value (Fernandez-Rivera and Klopfenstein, 1989a). Generally, leaves and husks are more digestible than cob and stem. This difference in material quality leads to different grazing gradients because cattle are selective animals. Lamm and Ward (1981) examined the composition changes of corn crop residues when grazed by mature beef cows. Leaves and husks decreased by 30.6%, while stalks and cobs increased by 54.8 and 13.1%, respectively, proportionally on the residue mass. Furthermore, they observed that cows selectively consume the remaining grain, leaves and husks, cobs, and stalks, in that order.

The objective in grazing the residue is that it be used by the animal as efficiently as possible, thus becoming the animal the main agent for the disappearance of the residue in the area. Lehman et al. (2021) conducted a three-year study investigating the effects of residue FF, in which strip grazing (SG), continuous grazing (CG), and no grazing control (CT) techniques were evaluated. They observed in the CG that total residue availability was 8,420 kg/ha before and 3,979 kg/ha after grazing, while SG was 9,212 kg/ha before and 4,535 kg/ha after grazing. These results show that the percentage of residue disappearance varies by approximately 50 to 52%, respectively. In addition, the authors reported a higher disappearance of the most digestible components (leaves/husks), with 3,757kg of DM/ha pre-grazing and 1,068 kg of DM/ha post-grazing. Stalker et al. (2015) investigated the effects of utilizing two different stocking rates (2.5 and 5.0 AU/ha) while grazing residue in a five-year study. They found a reduction in total residue mass of approximately 25% by grazing. In addition, a reduction (57 and 42%) in husks and leaves was observed in the 2.5 AU/ha treatment, while in the 5.0 AU/ha grazing treatment, husks and leaves were reduced by 82 and 47% after grazing. However, the mass of cob and stem was similar (3,448 and 1,214 kg/ha, respectively) before and after grazing, demonstrating that cattle avoid consuming cob and stem, which are less digestible fractions, as mentioned previously.

Residue grazing occurs at different times of the year depending on weather, resource availability, and farm location (Ulmer et al., 2019). Weathering is one of the main factors causing residue disappearance. As in grazing, the most digestible materials are the first to disappear by weathering (Fernandez-Rivera and Klopfenstein, 1989a; Lamm and Ward, 1981; Lehman et al., 2021; Stalker et al., 2015). Lehman et al. (2021) observed a reduction of 22% (1,884 kg/ha) of initial mass by weathering from September to November. Stalker et al. (2015) reported similar losses by weathering, about 1,686 kg/ha of residue (22%), but at a different time of the year (November to February). Russell et al. (1993) showed that weather plays a key role in residue grazing. In a three-year experiment grazing corn residue, heavy rainfall followed by warmer temperatures in year 3 increased the disappearance of the most nutritive and digestive compounds. This change was reflected by reduced animal performance, due to alteration in the residue nutritional value, in year 3 compared to years 1 and 2.

The disappearance of more digestible components of the corn residue, either by weathering or grazing selectivity, will result in a change in the nutritive value of the diet (Fernandez-Rivera and Klopfenstein, 1989a; Lamm and Ward, 1981; Lehman et al., 2021; Stalker et al., 2015). Lamm and Ward (1981) examined changes in the nutritional composition of corn crop residues. They observed a decline in CP and IVOMD values, averaging 8.8 and 72.0% pre-grazing and 8.2 and 59.2% post-grazing, respectively, when analyzing the residue components together, without separating the plant components, demonstrating a decline in the nutritional quality of the residue as grazing occurs. Similarly, Lehman et al. (2021) found no differences in NDF, CP, or OM among treatments pre-grazing. However, in post-grazing data, grazed paddocks had increased ADF and decreased CP compared with ungrazed paddocks. In both experiments, residue components were not analyzed separately. Consequently, this change was likely influenced by the difference in residue composition as selective grazing was observed in both experiments.

Meanwhile, the nutrient contents in the residue do not change when analyzed and compared individually, as observed by Stalker et al. (2015). They found similar values of ash, NDF, and IVOMD before and after grazing for all components. Furthermore, similar CP content was found at both sampling dates for all plant parts except the husk. Fernandez-Rivera and Klopfenstein (1989), evaluating grazing under different stocking rates (2.47 and 4.69 AU/ha), found that the CP content of corn residue was not different before (4.7 and 4.9%) and after grazing (5.1 and 4.7%) for the stocking rates evaluated, respectively. In addition, no differences were observed in leaf and husk CP content, 5.6% before and 4.8% after grazing. Also, greater CP contents were found in the leaves, while lower amounts were found in the cob, husk, and stem. Lamm and Ward (1981) observed that at the beginning of the experimental period, grain had the highest CP and IVOMD content (12.6 and 95.2%, respectively) when compared to the other residue components. The leaves had greater CP content (7.3%) and were more digestible than the cobs or stems. In addition, greater ADF contents were observed in the stems compared to husks and leaves (43.7 vs. 34.7 and 34.5%, respectively).

Integrated crop-livestock system (ICLS) is a production strategy growing in Brazil in recent years. It aims to use different production systems to take advantage of soil, plant, and animal characteristics in a complementary way within the same area. This system can be separated by a spatial-temporal difference in succession or rotation, promoting benefits for all activities (Russelle et al., 2007; Sulc and Franzluebbers, 2014). The diversification promoted by this system allows the farm to become less vulnerable to market fluctuations and climate-related problems than traditional production systems (de Albuquerque Nunes et al., 2021) Furthermore, it can promote greater profitability due to the reduction in production costs through complementarities between crop and livestock, reducing the dependence on factors beyond the producer's control (Wilkins, 2008; Ryschawy et al., 2012; Peyraud et al., 2014).

Research with ICLS using soybean cultivation showed greater profitability of integrated systems. de Albuquerque Nunes et al. (2021) demonstrated greater profitability at heavier grazing intensities. Thirty-eight percent higher profits were observed in the two higher grazing intensities (intense and moderate) compared to the two lower intensities (moderate-light and light grazing), in addition, the higher intensities were 112% more profitable than the control treatment. De Oliveira et al. (2014) used the same treatments but with a shorter time interval and found profitability increases of 27% between the evaluated intensities and 100% compared with the control. The average values were 669, 526, and 334 USD\ha, respectively.

The substitution of specialized grain, fiber, meat, and milk production systems for more complex crop-livestock integration systems goes beyond the potential economic performance to the change in the global management of the property, generating impacts on the environment, on the components involved in the system, and on the soil. These impacts can range from positive to negative. Improving soils' physical, chemical, and biological properties is a key issue in developing more sustainable agricultural production systems, and corn crop residue can be inserted into this context by bringing a new component to the system. However, understanding the effects of grazing in this system is fundamental, especially to understand its real impact on subsequent crop production and consequent profitability.

Previous research has shown that grazing cattle can negatively affect soil's physical properties (Betteridge et al., 1999; Krenzer et al., 1989; Mapfumo et al., 2011)

There is a potential for animal trampling to impact soil physical properties through increased compaction, with a consequent reduction in crop productivity (Clark et al., 2004). Soil compaction results from an increase in soil density which leads to a decrease in soil porosity, reduced soil aeration and water infiltration rate, delayed plant emergence, impaired root development, and reduced oxygen and nutrient transport (Batey, 2009; Peng and Wang, 2012) The extent of compaction depends on factors such as soil texture, organic matter, and moisture, which is the reason for the different results among studies that evaluated the effect of grazing animals on soil compaction and the lack of clarity on its real impact (Greenwood and McKenzie, 2001; Mapfumo et al., 2011; Peng and Wang, 2012; Rakkar and Blanco-Canqui, 2018b). Grazing compaction results from animal trampling due to the force imposed by the animal while grazing. The animal's type, age, and weight per unit area of ground determine the force exerted by the animal. The static pressure of a cow, for example, can range from 98 to 192 kPa (Taboada et al., 2011), which is more than the static pressure of tractors, which ranges from 27 to 68 kPa depending on track width and tractor weight (Rakkar et al., 2017; Rakkar and Blanco-Canqui, 2018a). Thus grazing can cause soil compaction by exerting similar or higher pressures on the soil than agricultural machinery (Greenwood and McKenzie, 2001). When in motion, the animal practically doubles this pressure since when walking, the animal will be supported by two or three claws, making the concentration of weight on these claws greater than when it is distributed on four claws (Greenwood and McKenzie, 2001). However, the effects of compaction by grazing animals are limited to the surface layer of soil, between 0-10 cm, and will not be sufficient to limit root development. Furthermore, these effects are not prolonged due to the improvement promoted by natural processes, such as when the soil temperature reaches below freezing, and by the biological action of roots and soil organisms (Bell et al., 2011; Clark et al., 2004; Greenwood and McKenzie, 2001).

Stocking rate is another relevant factor in soil compaction due to the number of animals in the area and its effects mentioned above. It will also determine the rate of residue removal. High residue removal rates (> 50%) can reduce the capacity of the soil to retain water and reduce the protection of the soil against weathering agents (wind and rain), exposing the soil to erosion (Blanco-Canqui et al., 2016a, 2016b; Blanco-Canqui and Lal, 2009; Rakkar and Blanco-Canqui, 2018a). Soil penetration resistance (PR) and bulk density (BD) are the main parameters measured to determine the compaction of the soil. High PR values are related to animal weight, stocking rate, and water table depth

(Lehman, 2015). Rakkar et al. (2017) evaluated the cumulative effect of 16 years of corn residue grazing by studying three systems: fall grazing (4.4-6.2 AU/ha), spring grazing (9.3-13.0 AU/ha), and control (no grazing). Authors observed an increase in PR of 0.84 MPa with high stocking rates (9.3-13.0 AU/ha), while grazing at recommended stocking rates (4.4 - 6.2 AU/ha) did not affect soil compaction. Rakkar and Blanco-Canqui (2018), in their meta-analysis, examined nine studies that reported PR by grazing. In six studies, an increase in penetration resistance by grazing was observed, while the remaining three reported no effect. Moreover, there was a variation between 0.27 to 0.84 MPa in the topsoil layer. The authors explain that this variation may be due to differences in stocking rate, type of animal, and grazing period. Clark et al. (2004) evaluated soils managed in a corn-soybean rotation, grazed at consecutive 4-week intervals at a rate of 3.7 cows/ha, and found that penetration resistance to a depth of 10 cm increased in paddocks grazed in October and November. However, when the soil temperature was under 0°C subsequent production increased, showing that an animal's compaction can be easily reversed, as mentioned above. Bulk density has unclear results regarding the effect of residue grazing. Rakkar and Blanco-Canqui (2018) also evaluated the effect of residue grazing on BD in 14 studies and the results showed that in seven of these there was an increase in BD, in five studies no effect was found, and in two a reduction in BD values was observed. These differences can be explained by differences in soil moisture content at the time of grazing and differences in soil texture between the studies. The BD values were below the values that limit root growth according to USDA (2008), which considers values above 1.47 Mg/cm^3 for clay soils and 1.80 Mg/cm^3 for sandy soils limiting to root growth.

Residue grazing has been shown to increase soil nutrient availability in several studies (Agostini et al., 2012; Drewnoski et al., 2016; Maughan et al., 2009; Tracy and Zhang, 2008), although many believe that residue grazing will reduce soil nutrient availability. The N, P K, and some of the C consumed by animals are cycled through the excreta. Animal excreta in this system is an additional source of nutrients to the soil (Mambir et al., 2018), mainly via feces. The manure contains C and N, increasing soil organic matter (Russel et al., 2007). Furthermore, urine is another important form for nutrient return, mainly nitrogen. Agostini et al. (2012), evaluating the effects of four grazing strategies: closure (C), one grazing (OG), high stocking rate (HR), and farmer's management (FM), observed that nitrogen accumulation was significantly affected by the grazing strategies. The total N accumulation was higher under HR (215. 4 kg N/ha) than under the rest of the grazing strategies with C (147.8 kg N/ha), OG (170.0 kg N/ha) and

FM (202.4 kg N/ha). The authors observed that the RH and FM treatments had greater animal presence than C and OG, which led to greater organic matter deposition by animals (feces and urine), contributing to the recycling of N stock and increased crop production. Maughan et al., (2009) compared winter cover crops (WCCs), cool-season pastures (CSP), and continuous corn (CC) on soil properties and yield of corn (Zea mays L.). Authors observed total N values of 1.3, 1.6 and 1.8 g/kg for CC, CSP, and WCC treatments, respectively. Besides other factors, the authors cite that manure and cattle urine may have contributed a significant amount of the ingested N to the soil in the integrated treatments. Thus, residue grazing can increase soil organic matter levels and overall fertility in ICLS.

The impact of residue removal on grain yield is variable and inconclusive within the literature because of the complexity of factors that can affect subsequent crop yields after residue grazing (Blanco-Canqui and Lal, 2009; Karlen et al., 2014; Lehman et al., 2021). Studies have shown that grazing by cattle can negatively affect soil's physical properties (Betteridge et al., 1999; Krenzer et al., 1989; Mapfumo et al., 2011) and may reduce the productivity of subsequent crops. However, in more recent studies, grain yields have not been affected by the presence of animals (Clark et al., 2004; Drewnoski et al., 2016; Lehman et al., 2021; Stalker et al., 2015; Ulmer et al., 2019). Clark et al (2004) showed that grazing corn residue with beef cows had little to no effect on soybean yields the following growing season. Soybean plant populations did not differ between grazed and ungrazed paddocks for all three-years of this study. Stalker et al. (2015) observed that corn residue can be grazed without negatively impacting subsequent grain production. Drewnoski et al. (2016) found that stocking rates that would result in the intake of 10-22% corn residue had slight positive or no impacts on subsequent soybean or corn yields. Lehman et al. (2021) observed that residue removal could be approximately 50% when grazing occurs during the fall without negatively affecting subsequent corn yield. When evaluating the grazing method, they observed that the first strip had reduced yield compared to the second strip, the third strip being intermediate and not different from the first or second strip. This difference was explained by the location of the feeders and waterers in the first strip. Thus, the authors suggested that moving feeder and water locations as the strip fences are moved may also be a management strategy to decrease the concentration of cattle in a specific area.

These conflicting results of the impact of residue grazing on the subsequent crop can be influenced by different soil types, climates, and crop management (Wilhelm et al., 2004). Therefore, research is needed to understand the dynamics of residue use in ICLS and the effect of different stocking rates on all of the above characteristics with the use of residue for finishing animals on starch-rich diets.

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CHAPTER 1

Article 1 - Grazing snaplage residue as a roughage source for finishing beef cattle: effects on residue characteristics, cattle behavior and performance, and carcass characteristics

Manuscript will be submitted to the Journal "*Livestock Science*".

Preliminary version. The Journal Editorial Board will be able to suggest changes.

Abstract

The increasing use of snaplage in Brazil has increased interest in alternative uses of the abundant remaining residue post-harvest. The objective of this study was to evaluate different stocking rates of heifers grazing snaplage residue as an exclusive source of fiber on finishing phase performance. Immediately after the corn snaplage harvest, the area was divided into sixteen paddocks, and treatments were randomly assigned. The treatments were two stocking rates (SR): 1) low stocking rate (LS; 3.5 AU/ha), and 2) high stocking rate (HS; 7.0 AU/ha). The treatments were obtained by modifying the size of the paddocks. Crossbred beef heifers (n = 48; initial body weight = 275 ± 23 kg) were randomly allotted to 16 paddocks (3 heifers/paddock). Concentrate was fed ad libitum daily at 0600h. Data were analyzed using the MIXED procedure of SAS. Means were estimated using the LSMEANS statement and compared using the Tukey test. There was no SR x time effect ($P = 0.88$) on residue mass. There was less ($P < 0.01$) total residue mass for HS than LS and total mass decreased ($P < 0.01$) over time. The percentage of leaves and sheaths decreased over time ($P < 0.01$). There was no SR x time effect ($P \geq 0.16$) for behavior characteristics. However, there was a time effect ($P < 0.01$) for grazing, idleness, and ingestion. There was no difference between HS and LS for average residue intake ($P = 0.34$; 0.434 vs 0.478 kg/day, respectively), concentrate intake ($P = 0.84$; 7.72 vs 7.78 kg/day, respectively), and daily gain (ADG; $P = 0.94$; 0.952 vs 0.956 kg/day, respectively), The HS treatment increased ($P < 0.01$) gain per area (618 vs 309 kg/ha) compared to LS. In conclusion, the stocking rate did not affect the finishing phase performance of beef heifers but increasing the stocking rate increased gain per land area.

Keywords: Beef cattle, Crop-livestock integration, Corn residue, finishing system

1.0 | INTRODUCTION

Corn silage usage as a roughage source for finishing beef cattle has been increasing in Brazil (Bernardes and Castro, 2019). Within this scenario, the snaplage is increasingly being adopted in brazilian feedlots (Bernardes et al., 2022), which is composed of ear (cob and grain) and husks (Ferraretto et al., 2018). However, an abundant residue consisting of the leaf and stalk of the corn plant remains in the field. This residue is generally used as a ground cover for the subsequent no-till cropping practice. However, in the United States, grazing corn crop residue by cattle is a management practice used mainly in the Corn Belt and the Midwest (Lehman et al., 2021; Sulc and Tracy, 2007), being a low-cost feeding strategy for backgrounding and cow-calf operations cattle, especially in the fall and winter (Lawrence and Strohbehn, 1999; Lehman et al., 2021).

Finishing cattle on concentrate while grazing pasture, well-known in Brazil as termination intensive in pasture (TIP), is a management practice that is growing in Brazil year by year (Franco, 2019), especially in regions where there is high availability of co-products and concentrate feeds (de Oliveira et al., 2014; Patino et al., 2015). Although feedlots have been widely adopted in production systems, the operational and structural costs make the production process more expensive, so many producers have adopted the TIP (Moretti, 2015). This practice is based on providing levels of concentrate similar to those adopted in feedlots to grazing animals (Moretti, 2015). Thus, concentrate becomes the main source of nutrients in the diet (Moretti, 2015). In this system, the animals receive between 1.5 and 2% of body weight in concentrate (Franco, 2019). At this level of supplementation, the substitution effect occurs, in which the animal consumes less forage, allowing for increased stocking rates (Goes et al., 2005; Moore et al., 1999; Paterson et al., 2015). (Franco, 2020). On the other hand, a high level of starch-rich supplementation for grazing animals can lead to acidosis through rapid and excessive fermentation of rapidly fermentable carbohydrates(Owens et al., 1998). Acidosis can reduce the intake and consequently affect the performance of the animals (Schwartzkopf-Genswein et al., 2003), resulting in efficiency and production losses, affecting meat production and quality (Ladeira et al., 2018; Schwartzkopf-Genswein et al., 2003). In this scenario, fiber plays an important role in stimulating chewing and saliva production to balance the acids produced (Beauchemin, 1991).

Using snaplage residue in TIP may be an excellent alternative as a source of fiber to maintain rumen health and to achieve part of the energy requirement. However, in traditional TIP, stocking rates are adjusted based on the estimated productivity of the available forage (Congio et al., 2019; Rouquette, 2015) and it is possible to modulate forage growth dynamics using nitrogen fertilization (Homem et al., 2021) when the finishing takes place in the rainy season. This strategy allows for a constant quantity and quality of forage canopy without affecting animal performance, or it could also allow for adding animals and increasing the gain per land area. However, grazing corn crop residue has a different dynamic than grazing a growing forage. When grazing residue, animal performance can decline over time (Stalker et al., 2015) because of losses in quantity and quality of residue due to intake, trampling, and weathering (Lehman et al., 2021; Russell et al., 1993; Stalker et al., 2015).

We hypothesized that greater stocking rates on snaplage residue could affect animal performance and meat quality due to a reduction in the availability of residue and an increase in the proportion of less digestible components in the diet of finishing animals, and a higher risk of acidosis. However, increasing the stocking rate may promote greater gain per land area. Therefore, our objective was to investigate the effects of stocking rate on the characteristics of snaplage residue and animal performance and the gain per land area.

2.0 | MATERIALS AND METHODS

The experimental procedures of this study were approved by the Ethics and Animal Welfare Committee of the Federal University of Lavras (protocol number 008/2019).

2.1 | Experimental site and treatments establishment

The experiment was carried out at the Experimental Farm of the Universidade Federal de Lavras, Brazil (21°14′09" S, 45°58'35" W; 880m above sea level). This area has a subtropical humid mesothermal climate with dry winters (Köppen-Geiger climate classification: Cwa;Sá Júnior et al., 2012). Meteorological data (Fig. 1) were obtained from a weather station located 1,000 m from the experimental area.

Immediately after the corn harvest, the area was divided into twenty-four paddocks of which only sixteen were used in the current experiment and the treatments were randomly allocated. The treatments were stocking rates (SR) in the animal unit (AU; the animal unit was considered a bovine weighing 500 kg; Allen et al., 2001), namely: (1) **Low stocking rate (LS; 3.5 AU/ha)** and (2) **High stocking rate (HS; 7.0 AU/ha)**. The treatments were obtained by modifying the size of the paddocks for each treatment. The LS and HS paddock size were 0.6 and 0.3 ha, respectively. Forty-eight F1 heifers (Angus x Nellore; 276 ± 20 kg of body weight [BW] and 16 ± 1.3 months of age) were used as tester animals, with three in each paddock. The heifers were identified, weighed, treated against internal and external parasites, and housed in a pasture with proper forage allowance and water availability until the corn snaplage harvest. Immediately after the corn snaplage harvest, the animals entered the experimental area. The experimental grazing period lasted 96 days. The chemical composition of the corn snaplage residue was performed on day 30 of the experimental period and is described in Table 1. The Concentrate was fed ad libitum daily in the morning at 0600h. The concentrate was composed of corn: 87%, soybean meal: 3.5%, cottonseed meal: 3.9%, urea: 1.6%, and mineral: 4.0%. The composition (DM basis) of the concentrate was 90.6% (organic matter), 3.40 (NDF), 3.93% (iNDF), 16.6% (Crude protein), 75.7 (Starch), 3.91% (Ether extract).

2.2 | Experimental Evaluations

2.2.1 | Snaplage residue mass

Three samples were collected in each paddock at randomly selected locations, using frames measuring 1.5 x 1.4 m. Immediately after corn harvest for snaplage, the field was sampled for characterization and quantification of the initial snaplage residue mass in each paddock and this sampling was repeated every 15 days. After collection of the snaplage residue, morphological separations were performed. The snaplage residue samples were separated into leaf, stem, and sheath. The samples were oven-dried at 55°C for 72 h to a constant weight. The snaplage residue mass was considered as the sum of the morphological components of the corn.

2.2.2 | Animal behavior

During the experimental period, six visual observations of heifer behavior were performed, each lasting 12 hours. Data collection was performed by trained observers at 5-minute intervals. The behavioral variables collected were: grazing time, rumination time, feeding time at the bunk, and time in other activities (idleness).

2.2.3 | Nutritive value

The nutritive value of each morphological component of the snaplage residue mass and samples of concentrate were analyzed on day 30 of the experimental period. This nutritive value characterization was at the same time as the collection period for corn residue intake (item 2.2.4). A composite sample of each morphological component for each experimental unit was made. The corn residue and concentrate composite samples were ground in a Cyclotec mill (Tecator, Herndon, VA) to pass 1-mm screen. After grinding, the dry matter (DM) of each sample was obtained by oven drying at 100°C for 18 h (Method 934.01; AOAC, 2000). The crude protein (CP) concentration was calculated based on the N concentration (CP = total N × 6.25), which was determined using the Kjeldahl procedure (Method 920.87;AOAC, 2000). In the corn residue samples, the ash and protein-free neutral detergent fiber (NDF) was determined by the autoclave method at 105°C for 60 min (Pell & Schofield, 1993).

In the concentrate samples, ash and protein-free neutral detergent fiber (NDF) was determined by filter bottom crucible (Method 978.10; AOAC, 2000) and the ether extract (EE) was analyzed according to Method 920.39 (AOAC, 2000). Starch concentrations in the concentrate were measured according to an enzymatic method (Hall and Mertens, 2008), with thermostable α-amylase (Ankom Tchnology, Macedon, NY) and amyloglucosidase (Megazyme E-AMGDF, Bray, Co. Wicklow, Ireland).

Utilizing the proximal analysis of each component of snaplage residue (leaf, stem, and sheath) and its respective proportion in the mass of snaplage residue at each collection point (2.2.1), a chemical characterization of the residue was performed over time.

2.2.4 | Diet intake, nutrient intake and total nutrient digestibility

The individual intake of residue and concentrate were estimated on day 25 of the experimental period using fecal excretion and indigestible neutral detergent fiber (iNDF). Spot fecal samples were collected, and a composite sample was created for each animal for 3 days of collection. On the sampling days, the heifers were moved from the paddocks to a barn to collect feces directly from the rectum at times 07h00, 12h00, and 17h00, respectively. Titanium dioxide (TiO_2) was used to estimate the fecal excretion of animals. Ten (10) g of TiO_2 was wrapped in paper cartridge and provided daily to each animal through an esophageal probe. Chromic oxide (Cr_2O_3) was used to estimate the individual concentrate intake. The chromic oxide was included in the concentrate (0.15%) that was consumed by heifers. The chromic and titanium were provided for nine consecutive days, six for adaptation, and three for collection (Titgemeyer et al., 2001). Fecal samples were oven dried at 55 °C for 72 h to determine the DM concentration and air equilibrated, weighed, and ground in a Cyclotec mill (Tecator) to pass 2 and 1-mm screen (2-mm for iNDF analyses and 1-mm for other analyses). The fecal samples were analyzed for titanium dioxide and chrome oxide concentration, according to Myers et al. (2004), and Williams et al. (1962), respectively.

Fecal, snaplage residue mass, and concentrate samples were incubated in the rumen for 288 h to determine iNDF (Huhtanen et al., 1994). Two cannulated heifers fed with a diet consisting of marandu palisadegrass and corn-based concentrate (80:20) were used for iNDF estimation. Fecal excretion was used to determine the total amount of iNDF in feces. Thus, the estimated intake of iNDF per day was obtained. After that, iNDF from the diet (corn residue + concentrate) was sampled to estimate the intake.

The corn residue intake (CRI, kg/day) was obtained using indigestible neutral detergent fiber (iNDF) as the internal marker, as follows:

$$\text{CRI (kg/day)} = [(\text{FE} \times \text{iNDF in the feces}) - \text{iNDF in the concentrate}] / \text{iNDF in the corn residue}$$

where CRI = corn residue intake (kg/day), FE = fecal DM excretion (kg/day), iNDF in the feces = iNDF concentration in the feces (g/kg of fecal DM), iNDF in the concentrate = amount of iNDF that came from the concentrate (kg/day), and iNDF in the corn residue = iNDF concentration in the corn residue (g/kg DM). The total intake was obtained by the sum of the corn residue and concentrate daily intake.

The nutrient intake was calculated by snaplage residue and concentrate intake multiplied by their respective nutritive value. The coefficients of apparent total tract digestibility of the DM, OM, CP, EE, NDF, and starch were calculated using fecal excretion of the external titanium dioxide marker (Myers, 1991). The DM, OM, CP, EE, NDF, and starch concentrations of fecal samples were determined in the same way as described for the corn residue and concentrate nutritive value analyses. The apparent total tract digestibility (g/kg) was calculated as (% DM and nutrients in the diet - % DM and nutrients in feces)/(%DM and nutrients in diet). The apparent digestibility coefficients were calculated for DM, OM, CP, NDF, starch and EE.

2.2.5 | Animal performance

The animals were weighed at the beginning (day 0), at the end of the adaptation phase (day 15), at the middle of the experimental grazing period (day 50), and at the end of the experimental grazing period (day 96). Only the initial and final weights were used to determine the average daily gain (ADG), which were performed with 12h fasting of feed and water.

2.2.6 | Slaughter and sampling

After the 96-d experimental grazing period, the heifers were slaughtered in a commercial slaughterhouse using captive bolt stunning and jugular vein bleeding, followed by skinning and evisceration. The carcasses were then divided longitudinally into two halves to obtain the hot carcass weight and hot carcass yield. After 24 h of refrigeration at 2 °C, the subcutaneous fat thickness was measured between the 12th and 13th ribs of the left carcass using a graduated caliper at three-fourths of the length of the ribeye from the cranial portion. The ribeye area was also measured between the 12th and 13th ribs, outlined on transparency paper, and quantified after reading by the LI-3100 area meter (LI-COR Inc., Lincoln, Nebraska, USA).

A 2.54-cm-thick steak of the longissimus thoraces muscle was removed from the left carcass cranially from the 13th rib for intramuscular fat analysis. After the collection at the packing plant, the samples were transported and stored at -20 °C until analysis. The proximate composition analysis was performed on a 100g ground steak after removing subcutaneous fat, using Foodscan™ equipment (FOSS, Hillerod, Denmark) using the near-infrared range according to AOAC (2007).

Two (2) steak were used for a different maturation time (0, immediately after slaughter and 14 days postmortem). The same steaks pre-thawed at 4 ◦C were used for performance the CIE color index and both times (0 and 14). The steaks were removed from the vacuum packaging for exposure to oxygen for 30 minutes. Meat surface reflectance data were recorded from the average of five consecutive measurements using a CM-700 colorimeter spectrophotometer (Kˆonica Minolta Sensing Inc., Osaka, Japan), with an aperture of 8 mm, illuminant D65, 10˚ observer angle, and in specular component exclusion mode (SCE). From the readings obtained in SCE mode, brightness (L*), redness (a*), yellowness (b*), hue angle (h), and chroma (C*) values were determined. The cooking loss was performed on a grill until an internal temperature of 71 ˚C was reached, which was monitored using a handheld digital thermometer. After cooking, the steaks remained at room temperature until the temperature stabilized and were subsequently weighed (AMSA, 1995). Total cooking loss was calculated as the difference between the weight of the steaks before and after oven-broiling.

2.3 | Statistical analysis

The experiment was carried out in a completely randomized design with two stocking rates (low stocking rate and high stocking rate) and eight replications. The carcass characteristics, diet, digestibility, meat chemical composition, nutritive value, nutrient intake, and performance variables were analyzed using the PROC MIXED procedure of SAS 9.4 statistical software (SAS Inst. Inc., Cary, NC), considering the paddock as the experimental unit. The stocking rate (treatment) was considered as a fixed effect. The statistical model for data analysis was calculated as follows:

$$\boldsymbol{Yi = \mu + SRi + \gamma i}$$

Where Yi is the observed measurement in the ith stocking rate; μ is the overall mean; SRi = fixed effect associated with jth stocking rate, $j = 1, 2$; γi = random error associated with the ith SR.

The animal behavior, corn residue mass, and meat quality were analyzed by the PROC MIXED procedure (mixed models) of the SAS 9.4 statistical software using repeated measurements over time (evaluation periods). The data were analyzed by fitting mixed models (Littell et al., 2000). The effects of stocking rate and evaluation periods were considered fixed. The Akaike information criterion was used to choose the best (co)variance structure (Akaike, 1974). All variance components were estimated using the restricted maximum likelihood method. Treatment means were estimated using the LS MEANS statement and compared using the Tukey test. When interaction was significant then it was sliced by time. Significance was declared at $P \leq 0.05$ and trends when $0.05 \leq P \leq 0.10$. The statistical model for data analysis was as follows:

$$\boldsymbol{Yijz = \mu + SRi + \gamma i + EPz + (SR \times EP)jz + \varepsilon iz}$$

Where $Yijz$ is the observed measurement ith stocking rate of the zth evaluation periods; μ is the overall mean; SRi = fixed effect associated with jth stocking rate, $i = 1, 2$; = random error associated with the ith SR nested within replication; EPz = fixed effect associated with zth evaluation periods; $(SR \times EP)jz$ = fixed effect of interaction jth SR with the zth EP; εjz = random error associated with the jth SR, and the zth EP.

3.0 | RESULTS

3.1 Snaplage residue mass

There was no stocking rate x time interaction effect (*P* = 0.82; Fig. 2) on the residue mass. However, a SR effect for total mass was detected (*P* < 0.02) with less total mass for HS than LS (6,951 vs 7,696 kg of DM/ha, respectively). There was also a time effect (*P* < 0.01) with total mass decreasing over time (*P* < 0.01) from 9,659 to 5,162 kg of DM/ha in the HS, and from 9,685 to 6,434 kg of DM/ha in the LS.

The change of proportion of morphology components in the mass of residue over time (Fig. 3). A time effect (*P* < 0.01) was observed with % leaves and % sheath decreasing over time (*P* < 0.01), with an average of 29.3 and 22.3%, respectively at At the beginning of the experimental period (Initial) and 19.6 and 11.5%at the end of the experimental grazing period (final), respectively. On the other hand, the % stem increased over time,

with an average of 46.8 at adaptation and 71.3 at the end of the experimental period.

3.2 Animal behavior

There was no SR x time effect (*P* ≥ 0.16; Fig. 4) for behavior characteristics, and there were no differences (*P* ≥ 0.15) in ingestion, grazing, rumination, and idleness between SR. There was also no time effect (*P* = 0.16; Fig. 4d) for time spent in rumination. However, there was a time effect (*P* < 0.01) for grazing, idleness, and ingestion.

The grazing time (min/d) changed with time (*P* < 0.01, Fig. 4b), although it increased on day 30 compared to the adaptation period (145 vs 206 min/d). After this period the time spent grazing was 97 min/d at the end of the experimental grazing period (d 96). On the other hand, time spent in idleness and ingestion increased over time (*P* < 0.01; Fig. 4c), although idleness decreased on d 30 compared to the adaptation period (418 vs 357 min/d) after this period the time in this activity increased to 457 min/d at the end of the experimental grazing period (d 96). The time at the bunk (Fig. 4a) was similar until d 45 of the experimental period but increased on d 60 until the end of the experimental period.

3.3 Nutritive value

There were no treatment × time interactions detected (*P* ≥ 0.99; Table 2) for nutrient composition of residue. There were also no differences (*P* ≥ 0.14) in OM, NDF, CP or iNDF between treatments. However, a time effect for OM and CP was detected (*P* < 0.01). The OM increased over time, with initial period (92.3%) having greater OM than the final period. On the other hand, the CP decreased over time, with 4.1% in the initial period compared to 3.5% at the end of the experimental period.

3.4 Intake and Digestibility

There were no differences (*P* ≥ 0.65; Table 3) in digestibility of DM, OM, CP, NDF, starch, or EE between treatments.

Total intake and concentrate intake tended to be greater for LS (*P* = 0.07, *P* = 0.09, respectively; Table 4), than for the HS (2.83 and 2.66% of BW/day vs 2.66 and 2.51% of BW/day, respectively). However, a treatment effect for residue intake was not detected (*P* = 0.40), with LS (0.172% of BW/d) and HS (0.151% of BW/d).

There were no differences (*P* ≥ 0.14; Table 3) in intake of OM, CP, NDF, starch, or EE between treatments. No differences between SR were observed for forage DOMI and CP/DOM ratio (*P* = 0.44 and *P* = 0.88, respectively).

3.5 Performance

No differences between SR were observed (*P* ≥ 0.88*;* Table 5) in average daily gain, initial or final BW. Furthermore, there was no difference (*P* ≥ 0.34) between treatments for the residue, concentrate, or total dry matter intake.

The HS had a 100% greater (*P* < 0.01) gain per area than the LS treatment (618 vs 309 kg/ha, respectively).

3.6 Carcass characteristics and chemical composition

No differences between SR were observed for hot carcass weight and dressing percentage (*P* ≥ 0.35, Table 6). There were no differences in 12th rib fat thickness, ribeye area, and marbling score detected (*P* ≥ 0.12).

No differences between SR were observed (*P* ≥ 0.13) in initial or 24h pH and temperature.

The meat chemical composition was not different (*P* ≥ 0.37) between treatments.

3.7 Meat quality

There were SR x time interactions detected (*P* = 0.01; Table 7) for shear force. The shear force was greater in the HS than LS treatment at time O. The average of both treatments was greater at time 0 compared to time 14. However, there was no difference between the treatments at time 14.

There were no SR x time interactions detected ($P = 0.30$; Table 7) for cooking loss, L*, a*, b*, C*, and, h*. There were also no differences ($P \geq 0.32$) among SR for these variables. However, a time effect was detected ($P < 0.01$). For cooking loss, there was a 13.6% reduction at time 14 compared to time 0. On the other hand, the maturation process increased ($P < 0.04$) L*, b*, C*, and, h*.

4.0 | DISCUSSION

The capacity of ruminants to use coproducts, crops, and feeds inappropriate for human nutrition has been increasingly explored within the production system (Russelle et al., 2007b). Still, the use of coproducts has its particularities, especially the grazing of crop residue. Productivity in grazing systems, whether grass or residue, is linked to animal gain and gain per area, which means animal performance and stocking rate (Jones and Sandland, 1974; Pereira et al., 2020). The traditional TIP system maximizes individual performance once the concentrate becomes the main food source. It provides the protein, energy, and mineral supply required for the finishing phase, with grass as a source of fiber for maintaining rumen health. However, the stocking rate can vary because the high supplementation promotes the substitution effect where the animal substitutes concentrate for forage (Moore et al., 1999; Paterson et al., 2015). This effect allows for an increase in the stocking rate. In the TIP, the stocking rate varies during the seasons, from 5 to 6 AU/ha in the dry season and up to 10 AU/ha in the rainy season (Franco, 2020).

The grazing system has constant sprouting, growth, and senescence. This process results in the herbage mass, which is a balance between forage input (i.e. forage growth) and forage output (i.e. forage senescence and offtake) (Homem et al., 2021a). By understanding these dynamics, it is possible to make correct adjustments to the stocking rate. However, when grazing residue (TIR) instead of pasture, there is a considerable reduction in the amount available over time, as indicated by the residue mass result (Fig. 2). This reduction occurs due to the grazing of animals, trampling, and weather factors (Lehman et al., 2021; Russell et al., 1993; Stalker et al., 2015). Lehman et al. (2021) observed a reduction of 22% of initial mass by weathering from September to November. Also, they found a percentage of loss by grazing of approximately 50%. In other experiments (Stalker et al., 2015; Ulmer et al., 2019), similar losses have been reported due to weathering but at different times of the year (November to February). However, these authors found a reduction in residue mass of approximately 25% by grazing. These differences in grazing disappearance can be explained by differences in stocking rates, length of the grazing period, and weather during grazing (Ulmer et al., 2019). In the current experiment, a 46% reduction was observed for HS with an initial mass of 9,659 kg/ha pre-grazing and 5,152 kg/ha post-grazing. The availability of residue in LS was 9,685 kg/ha pre-grazing and 6,434 kg/ha post-grazing resulting in a reduction of 33%. However, approximately 27% of this material was lost to weathering (data presented in paper 1).

The traditional corn plant residue is characterized by leaf, sheath, husk, stem, and eventual remaining cobs, while the residue of snaplage is characterized by leaf, sheath, and stem. In both residues, the leaf is the component of faster disappearance either by climatic factors or grazing (Stalker et al., 2015). In their previous research, Stalker et al. (2015) observed that at a stocking rate of 5.0 AU/ha, husks and leaves were reduced by 82 and 47%, respectively and in the 2.5 AU/ha treatment, the were reduced by 57 and 42%, respectively, after grazing. The stem mass remained the same after grazing, regardless of the stocking rate used, demonstrating that cattle avoid consuming stem. However, in snaplage residue, where the availability of more digestible material is lower, animals are forced to consume a less digestible portion of the plant. The intake of this material reduces performance (Stalker et al., 2015).

The nutrient contents do not change over time in parts of the plant when analyzed and compared individually as observed by Stalk et al. (2015). They found similar values of ash, NDF, and IVOMD before and after grazing for all components. Furthermore, similar CP content was found at both sampling dates for all plant parts except the husk. Fernandez-Rivera and Klopfenstein (1989a), evaluating grazing under stocking rates (2.47 and 4.69 AU/ha), found that the CP content of corn residue was not different before (4.7 and 4.9% CP) and after grazing (5.1 and 4.7% CP) for the stocking rates evaluated, respectively. In addition, no differences were observed in the CP content of leaf and husk, 5.6% before and 4.8% after grazing. However, the disappearance of more digestible components of the corn residue either by weathering or grazing selectivity result in a change in the nutritive value of the diet (Fernandez-Rivera and Klopfenstein, 1989a; Lamm and Ward, 1981; Stalk et al., 2015; Lehman et al., 2021). Lamm and Ward (1981) examined changes in the composition of corn crop residues and observed a decline in CP (8.8 vs 8.2%) and IVOMD (72.0% and 59.2%) for pre-grazing and post-grazing, respectively. Similarly, Lehman et al. (2021) found no differences in NDF, CP, or OM among treatments pre-grazing. However, in post-grazing data, grazed paddocks had increased ADF and decreased CP compared with ungrazed paddocks. Although Lehman et al. (2021) did not statistically analyze, it is possible to note an increase in average NDF (74.4 vs 78.2%) and ADF (74.4 vs 78.2%) and a decrease in CP (3.9 vs 3.4%) and OM (92.3 vs 87.0%) when comparing pre-grazing and post-grazing respectively, in all treatments evaluated. This could explain the change of the diet over time in the current experiment (Table 3) in OM and CP. the increase of stem proportion in the residue mass (Fig. 3) resulted in an increase of 2% in OM content and decrease of 13% in CP content.

The greater disappearance in HS did not lead to changes in behavioral data compared to LS (Fig. 4). However, the time spent in grazing and idleness activities changed over time. These results can be explained by the change in the proportion of morphological components of the residue (Fig. 3), once the concentrate intake as a percentage of body weight did not change over time (data not shown). Animal selectivity and weathering were the main factors for the difference in the proportion of components over time. The time spent grazing (fig.4b) indicates that the time in this activity was affected by this residue characteristic. An increase in grazing time was observed at day 30 and a decrease in the time spent in this activity until the end of the experimental period (Fig. 4b). The different nutritional values and digestibility of residue components likely led the animals to initially seek higher digestibility components (Fernandez-Rivera and Klopfenstein, 1989a; Gutierrez-Ornelas and Klopfenstein, 1991; Lehman et al., 2021; Stalker et al., 2015). Thus, with the disappearance of the more digestible components, the animal likely does not spend as much time looking for more digestible material as the area is more uniform, predominantly composed of stem or sheath attached to the stem. In addition, less time grazing can be explained by the fiber in this system acting only to maintain rumen health. The stem fiber is characterized by low-quality material. Thus, the animal needs less material to reach the level needed to maintain rumen function resulting in no difference in rumination time (Fig. 4d) observed with reduced grazing time and an increase in idleness time (Fig. 4c).

Increasing the stocking rate from 3.5 AU/ha to 7 AU/ha was not enough to alter the performance because both treatments ultimately received the same diet (Table 1). The same amount of concentrate was available for both treatments. The fact that concentrate was fed ad libitum could lead to acidosis as animals on grazing systems consume diets that are rich in rapidly fermenting carbohydrates (Owens et al., 1998). In addition, no adaptation diet was used as the aim was to challenge the animals to the potential fiber use condition, and when adaptation is eliminated or the diet changed rapidly, the animals are predisposed to the risk of acidosis (Goad et al., 1998; Coe et al., 1999). It was therefore expected that a reduction in the amount of snaplage residue available in HS treatment would result in increased acidosis, thereby affecting performance. However, both treatments had a similar proportion of components in the mass of the residue (Fig. 3). Furthermore, we hypothesized that the leaf would finish first in the HS treatment, leading to a reduction in performance when compared to the LS treatment because the leaf is more a nutritive and digestible material than the stem and sheath. Thus, an increasing stocking rate would result in a more rapidly increasing intake of the animals of this material in the HS treatment. However, the lower mass in the HS treatment did not result in lower leaf proportion since the disappearance of most digestive morphological components happened proportionally at the same time in both treatments (Fig. 2 and 3) due mainly to weathering, as mentioned previously.

The similarity of the diet in both treatments led to similar digestibility, nutrient intake, and residue intake per body weight percentage since the residue was not limiting in both treatments, with 5,162 and 6,434 kg DM/ha remaining in the HS and LS treatments, respectively, at the end of the experimental period. Thus, the animals performed similarly in both stocking rates because, although consuming low-quality material, this material represented approximately 5% of the diet (Table 5) with an intake of less than 0.2% of body weight (Table 4), resulting in similar feed efficiency. Our results indicate that increasing the stocking rate from 3.5 AU/ha to 7 AU/ha without affecting individual animal performance increases gain per area (Table 5). The HS had the greatest bodyweight gain per area, with an increase of 100% compared with the LS (Martha et al., 2012). Increasing the stocking rate allows you to double the number of animals and maximize the use of land and residue without affecting the quality of the finished carcass (Table 6) since there was no change in the data of chemical and physical characteristics change in the data of chemical and physical characteristics.

The similarity in performance results was also reflected in the meat quality results. We had hypothesized that increasing the stocking rate would result in decreased quality and quantity of residue resulting in lower performance and consequently affecting the meat quality in the HS treatment. However, the higher stocking rate (7.0 AU/ha) evaluated did not result in limiting residue or decreased animal performance. Thus, it is unsurprising that nearly all meat quality parameters were not affected by the stocking rate The no difference in performance results was also reflected in the meat quality results.

Although we hypothesize there was a possible difference due to acidosis in the HS treatment, since acidosis can affect marbling and fatty acid profile in meat from ruminants (Ladeira et al., 2018), the previous data showed that both treatments had no difference in dietary quantity and composition. (ASTM Committee, 2011; Miller et al., 1995; Destefanis et al., 2008)

5.0 CONCLUSION

Using a higher stocking rate (7.0 AU/ha) in the current experiment proved to be an excellent strategy for Termination Intensive in the Residue system, as it did not affect animal performance, leading to an increase in the gain per area.

Our results suggest that future studies are needed to evaluate greater stocking rates (>7 AU/ha) in a TIR system. Since, unlike TIP, in TIR the quantity and quality of residues decreases over time, it could be worthwhile to evaluate a step-up concentrate diet to ensure nutritional requirements are met as residue quantity and quality decreases.

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TABLES AND FIGURES

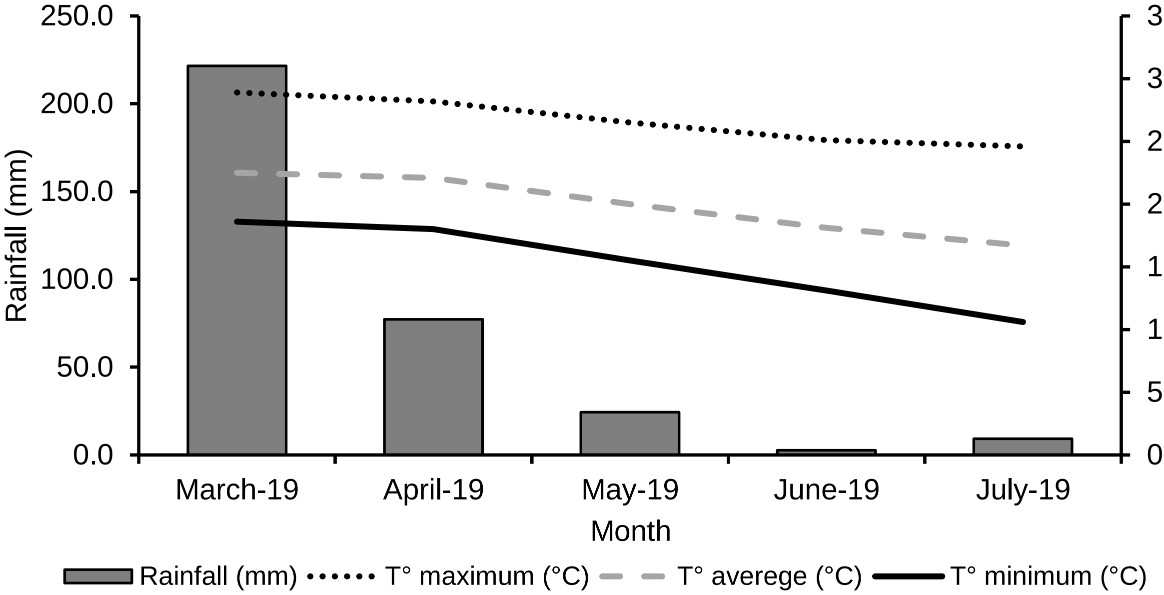

Figure 1. Mean monthly temperatures and rainfall in Lavras, Brazil, during the experimental period

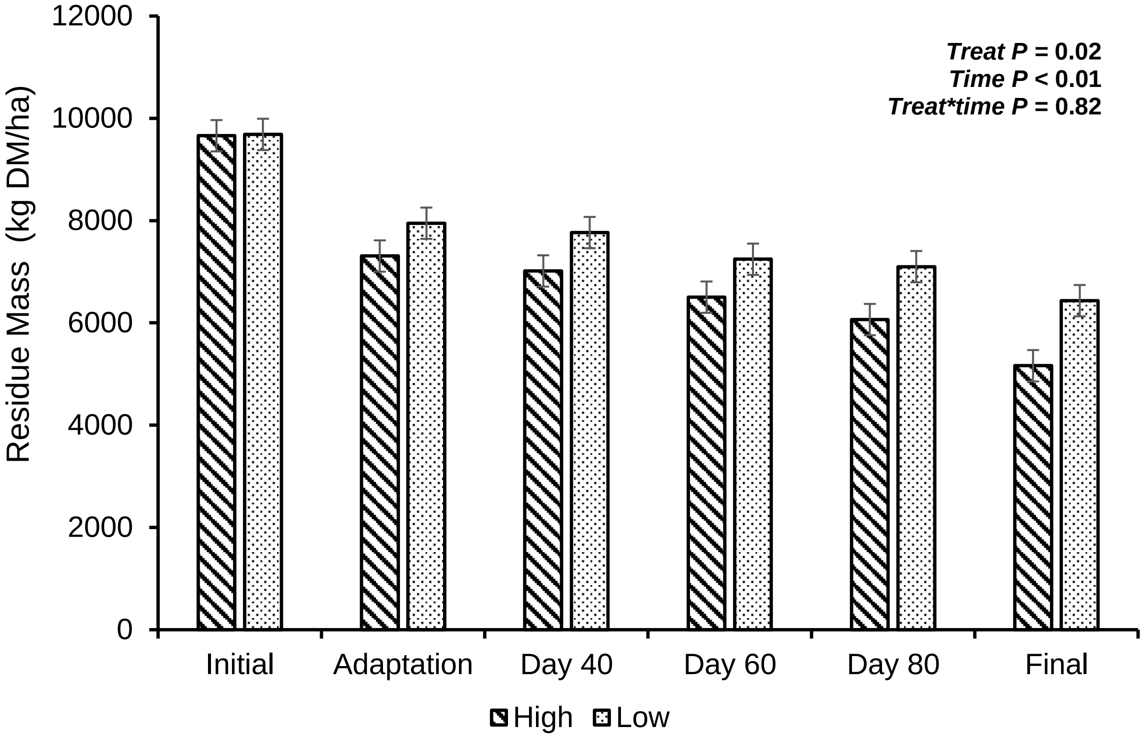

Figure 2. Effects of stocking rate (high stocking rate (HS), 7.0 AU/ha and low stocking rate (LS), 3.5 AU/ha), and period (initial, adaptation (d 15), d 40, d 60, d 80, and final (d 96); Error bars represent the SEM

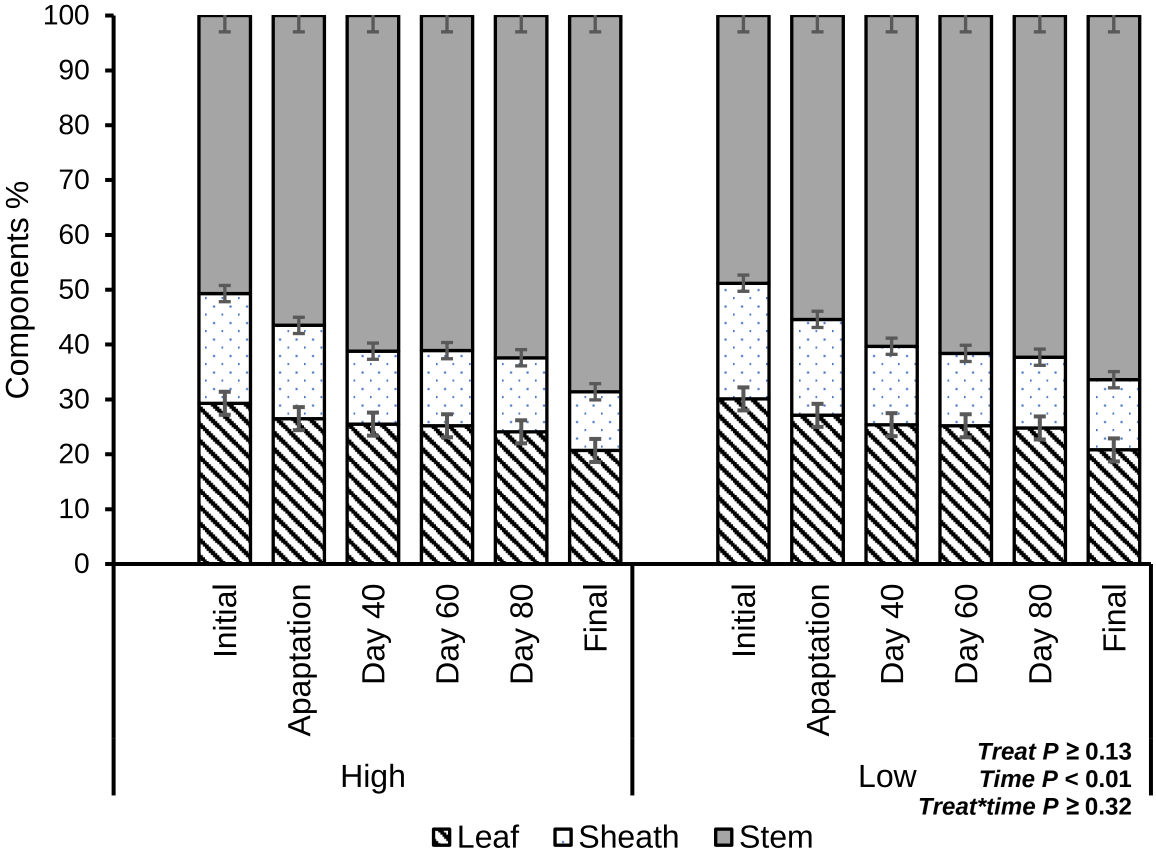

Figure 3. Effects of stocking rate (high stocking rate (HS), 7.0 AU/ha and low stocking rate (LS), 3.5 AU/ha), and period (initial, adaptation (d 15), d 40, d 60, d 80, and final (d 96); Error bars represent the SEM

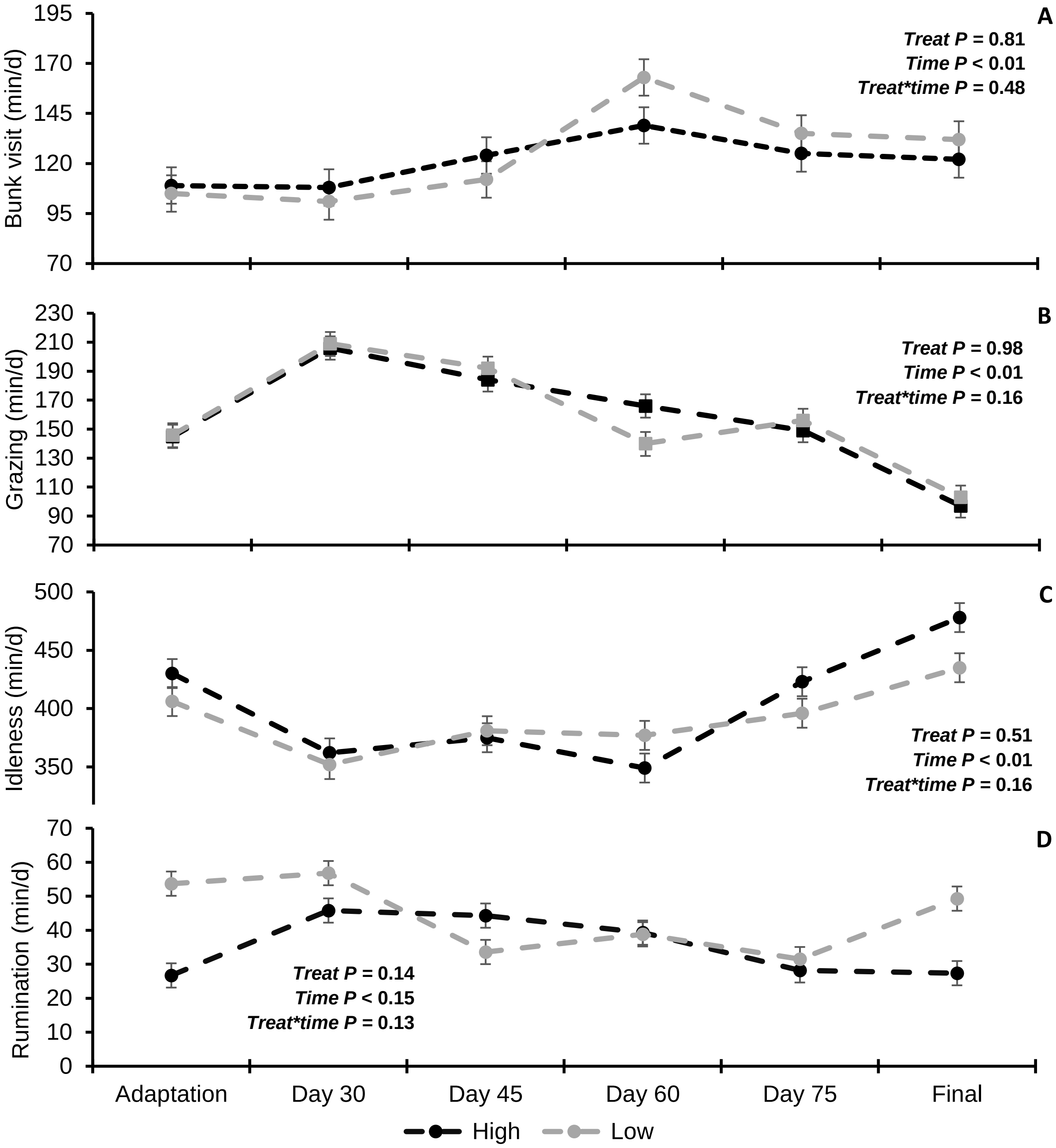

Figure 4. Effects of stocking rate (high stocking rate (HS), 7.0 AU/ha and low stocking rate (LS), 3.5 AU/ha), and period (adaptation (d 15), d 30, d 45, d 60, d 75, and final (d 96); Error bars represent the SEM.

Table 1. Effect of stocking rate on day 30 of the experimental period on the nutrient composition of each snaplage residue component

Item	**Treatments[b]**		**SEM[a]**	***P-value***
	HS	**LS**		
Leaf				
Organic matter, %	85.7	87.4	1.44	0.26
apNDF[c], %	63.4	66.1	1.81	0.17
iNDF[d], %	38.2	36.3	2.66	0.50
Crude protein, %	5.84	6.07	0.35	0.54
Sheath				
Organic matter, %	92.9	94.1	0.73	0.13
apNDF[c], %	75	77.3	2.69	0.40
iNDF[d], %	36.3	39.7	2.93	0.27
Crude protein, %	3.96	4.38	0.31	0.20
Stem				
Organic matter, %	95.5	96	0.4	0.26
apNDF[c], %	82.2	82.4	1.7	0.94
iNDF[d], %	46.6	44.6	1.63	0.25
Crude protein, %	2.89	2.89	0.11	0.98

[a] Standard error of the means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[c] apNDF: Neutral detergent fiber corrected to ash and protein

[d] iNDF: Indigestible Neutral detergent fiber

Table 2. Effect of two stocking rates over time on nutrient composition of the residue from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Treatments**[b]		**SEM**[a]	***P-value***		
	HS	**LS**		**treat**	**time**	**treat* time**
Organic matter, %						
Initial	92	92.7	0.56	0.48	<0.01	0.99
Adaptation	92.6	93.2				
Day 40	92.7	93.3				
Day 60	93.1	93.6				
Day 80	93.4	93.9				
Final	93.7	94.1				
apNDF[c]***, %***						
Initial	50.2	52.3	1.14	0.20	0.99	0.99
Adaptation	54.2	56.3				
Day 40	55.1	57.1				
Day 60	57	59.6				
Day 80	59.9	62.1				
Final	62	64.2				
iNDF[d]***, %***						
Initial	40.5	43.1	1.81	0.20	0.99	0.99
Adaptation	40.8	43.7				
Day 40	40.8	43.8				
Day 60	40.7	43.8				
Day 80	40.5	43.7				
Final	40.2	43.4				
Crude protein, %						
Initial	3.9	4.2	0.23	0.29	<0.01	0.99
Adaptation	3.7	4				
Day 40	3.7	3.9				
Day 60	3.6	3.8				
Day 80	3.5	3.7				
Final	3.4	3.6				

[a] Standard error of the means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[c] apNDF: Neutral detergent fiber corrected to ash and protein

[d] iNDF: Indigestible Neutral detergent fiber

Table 3. Effect of two stocking rates on apparent digestibility of the diet from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Treatments**[b]		**SEM**[a]	***P-value***
	HS	**LS**		
DM[c]***, %***	80.8	79.2	2.37	0.39
OM[d]***,%***	80.8	79.7	2.31	0.44
CP[e]***, %***	82.8	82.0	1.67	0.61
apNDF[f]***, %***	35.0	35.8	4.29	0.89
Starch, %	92.2	91.5	1.57	0.43
EE[g]***, %***	62.2	60.1	3.87	0.68

[a] Standard error of the means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[c] DM: Dry matter

[d] OM: Organic matter

[e] CP: Crude protein

[f] apNDF: Neutral detergent fiber corrected to ash and protein

[g] EE: Ether extract

Table 4. Effect of two stocking rates on Intake %BW from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Treatments**[b]		**SEM**[a]	***P-value***
	HS	**LS**		
Total, *% BW/d*	2.66	2.83	0.088	0.07
Residue, *% BW/d*	0.151	0.172	0.027	0.40
Concentrate, *% BW/d*	2.51	2.66	0.052	0.09
OM[c]***,*** *% BW/d*	2.39	2.53	0.061	0.16
CP[d]***,*** *% BW/d*	0.421	0.445	0.012	0.19
apNDF[e]***,*** *% BW/d*	0.20	0.21	0.022	0.36
Starch, *% BW/d*	1.90	1.99	0.043	0.14
EE[f]***,*** *% BW/d*	0.098	0.101	0.001	0.42
DOMI[g]***,*** *kg/d*	5.50	5.77	0.243	0.44
CP/DOM[h]***,*** *g/kg*	222	223	5.3	0.88

[a] Standard error of the means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[c] OM: Organic matter

[d] CP: Crude protein

[e] apNDF: Neutral detergent fiber corrected to ash and protein

[f] EE: Ether extract

[g] DOMI: Digestible organic matter intake

[h] CP/DOM: Crude protein/digestible organic matter ratio

Table 5. Effect of two stocking rates on performance from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Treatments**[b]		**SEM**[a]	***P-value***
	HS	**LS**		
Body weight, *kg*				
Initial body weight	276.0	275.6	7.60	0.88
Final body weight	365.0	364.2	14.91	0.93
Average daily gain, *kg/d*	0.952	0.956	0.132	0.94
Dry matter intake, *kg/d*				
Residue,	0.434	0.497	0.060	0.34
Concentrate,	7.72	7.78	0.381	0.84
Total,	8.15	8.27	0.322	0.66
Feed efficiency, *G:F*	0.114	0.112	0.011	0.76
Gain per area, kg/ha	618	309	54	<0.01

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

Table 6. Effect of two stocking rates on treatments on carcass characteristics and chemical composition from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Treatments**[b]		**SEM**[a]	***P-value***
	HS	**LS**		
Hot carcass weight, *kg*	190.9	191.6	8.54	0.92
Dressing percentage. %	52.2	52.7	0.35	0.35
12th rib fat thickness, *mm*	***3.12***	3.59	0.312	0.12
Ribeye area, *cm²*	63.3	62.0	1.23	0.39
Initial carcass pH	6.29	6.34	0.034	0.40
24h carcass pH	5.82	5.87	0.021	0.13
Initial Temperature *(°C)*	31.7	31.4	0.60	0.71
24h temperature *(°C)*	7.3	7.1	0.22	0.30
Marbling score[C]	366	373	5.8	0.43
Chemical composition				
Collagen, %	1.24	1.23	0.051	0.83
Protein, %	22.1	22.0	0.10	0.38
Fat, %	2.21	2.46	0.204	0.39
Moisture, %	71.3	71.1	0.17	0.37
Ash, %	3.11	3.58	0.095	0.42

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[C] Calculated according to Dow et al. (2011)

Table 7. Effect of two stocking rates on treatments on on meat quality from finishing heifers grazing snaplage residue and fed ad libitum concentrate

Item	**Time 0**		**Time 14**		**SEM**[a]	***P-value***		
	HS	**LS**	**HS**	**LS**		**treat**[b]	**time**	**treat * time**
Cooking from loss, *g*	22.1	22.6	18.9	19.7	0.72	*0.41*	*<0.01*	*0.78*
L*	43.0	43.5	44.2	44.5	0.42	*0.35*	*<0.01*	*0.78*
a*	20.4	20.1	19.7	19.7	0.61	*0.76*	*0.256*	*0.82*
b*	13.3	13.2	15.4	14.8	0.29	*0.33*	*<0.01*	*0.30*
C*	24.4	23.9	24.9	25.3	0.55	*0.98*	*0.05*	*0.34*
h*	33.8	33.4	38.6	37.4	0.73	*0.56*	*<0.01*	*0.36*

[a] SEM: Standard error of means

[b]Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha)

[c] Least squares means within a row with different superscipts differ at $P \leq 0.05$

[d] Warner-Bratzler shear force

CHAPTER 2

Article 2 - Grazing snaplage residue as a roughage source for finishing beef cattle: effects on soil physical and chemical properties and subsequent crop yield

Manuscript will be submitted to the Journal "*Livestock Science*".

Preliminary version. The Journal Editorial Board will be able to suggest changes.

Abstract

Use of snaplage residue in an integrated crop-livestock system (ICLS) system by adding beef production between two corn crops. The ICLS allows for enhanced profitability with efficient land use. Corn residue grazing may be an excellent alternative management practice in this system. The objective of this study was to evaluate the impact of residue grazing on the soil physical and chemical characteristics and subsequent crop yield, as well as the. Immediately after the corn snaplage harvest, the area was divided into twenty-four paddocks, and treatments were randomly assigned. The treatments were two stocking rates (SR): 1) low stocking rate (LS; 3.5 AU/ha), and 2) high stocking rate (HS; 7.0 AU/ha) and ungrazed control (CT). The treatments were obtained by modifying the size of the paddocks. Crossbred beef heifers (n = 48, initial body weight = 275 ± 23 kg) were randomly allotted to 16 paddocks (3 heifers/paddock) grazed. Data were analyzed using the MIXED procedure of SAS. The total mass, residue mass, weeds mass, and grass mass means were estimated using the LSMEANS statement and compared using the Tukey test. For physical and chemical characteristics and subsequent yield, pre-planned contrasts were CT vs. HS+LS and HS vs. LS with a significance $P \leq 0.05$. Multivariate analysis was performed using the principal component analysis method. Initial residual mass was similar for all treatments (9,600 kg DM/ha). There was less final mass for HS ($P < 0.01$) than CT. There was also less total pre-planting mass for HS and LS ($P < 0.01$) than CT. No grazing or stocking rate effects were detected ($P \geq 0.22$) for penetration resistance. The total nitrogen returned was increased by grazing (82% compared to ungrazed; $P < 0.01$). The macronutrients phosphorus (P) and potassium (K) were also increased with grazing (28 and 42%, respectively). The total yield mass increased by grazing (15% compared to ungrazed; $P \leq 0.04$). In conclusion, using snaplage residue for finishing cattle allowed the addition of beef production between corn crops, which positively affected subsequent corn yield.

Keywords: beef cattle, corn production, corn residue, intensification, integrated crop-livestock**.**

1.0 | INTRODUCTION

The number of farms adopting the integrated crop-livestock system (ICLS) is growing due to increasing concern with environmental preservation, impacts of human activity on food production, food security, natural resources conservation as well as the extension of crop areas to the detriment of pasture areas (Gupta et al., 2012; Russelle et al., 2007a; Wright and Wimberly, 2013). As a result, in recent decades, the intensification has increased production per unit of area in developed countries (de Albuquerque Nunes et al., 2021. The ICLS maximizes the use of resources and increases production via interaction and mutual benefit between crops and livestock by increasing the total production compared to the sum of its individual components (Soussana and Lemaire, 2014). Furthermore, it allows the use of the land during the whole agricultural year, where agricultural production is not possible year-round due to a mild winter season.

Brazil is the second-largest beef producer in the world (USDA, 2019). In occupyng a distinguished position in corn grain production as the third-largest producer in the world (USDA, 2022), with 19.8 million hectares planted in the last harvest(CONAB, 2022). This production takes place within a period of nine months of the year or more, depending on the objective of the crop (Lima et al., 2022), divided into two seasons, the first usually beginning in September and, the second in February (Lima et al., 2022), depending on which part of the country the farming operation is located. This inter-crop interval which can be corn followed by corn or often corn followed by soybean (Daniel et al., 2019) is an excellent opportunity for integration with livestock, especially when using snaplage that allows a greater interval between crops due to an earlier harvest timeline when compared to harvesting corn for grain (Ferraretto et al., 2018).

Ensiling of the corn ears (grains, cobs, and husks), also known as snaplage has been increasing in Brazil in recent years and is currently adopted in about 12% of Brazilian beef cattle finishing diets as the method of grain processing (Bernardes and Castro, 2019). The residue (stalks and leaves) resulting from the harvest process degrades naturally, favoring the cycling of nutrients, providing organic matter for the soil as well as physical cover for the no-till system for the next crop which might decrease soil erosion. However, the abundant corn residue in this system can be used as a roughage source in ruminant diets, exploiting the ruminant’s capability to utilize crops and especially residues that are not part of the non-ruminants diet (Russelle et al., 2007a).

Corn residue grazing technology is widely used in the U.S.A, especially the Midwest in cow-calf operations (Lawrence and Strohbehn, 1999; Sulc and Franzluebbers, 2014). This management practice is still not yet very common in Brazil, but it has a huge potential to be explored, considering the increasing the Brazilian corn productivity. Residue grazing provides nutrients to ruminants, allowing producers to utilize it as a low-cost alternative compared to traditional fall and winter feeding (Lawrence and Strohbehn, 1999; Lehman et al., 2021). Grazing residue would eliminate costs related to harvesting, transportation, processing, storage, and feeding.

Grazing the residue has been a concern for producers and researchers since the results are still unclear about its effect (Bell et al., 2011; Rakkar and Blanco-Canqui, 2018). Compaction or the removal of the biomass cover could affect the physical characteristics of the soil negatively (Allan et al., 2016; Bell et al., 2011; Clark et al., 2004). In addition, grazing extracts nutrients that would potentially return to the system via degradation affecting the chemical composition (Rakkar and Blanco-Canqui, 2018). On the other hand, there are several studies showing that residue grazing does not negatively affect the soil or the subsequent crop yield (Lemaire et al., 2014; Russelle et al., 2007a)

Previous research has shown that cattle grazing can lead to negative effects on soil properties (Krenzer et al., 1989; Betteridge et al., 1999; Mapfumo et al., 1999), Residue grazing has been shown to increase soil nutrient availability in several studies (Agostini et al., 2012; Drewnoski et al., 2016; Maughan et al., 2009; Tracy and Zhang, 2008). The N, P K, and some of the C consumed by animals are cycled through the excreta. The animal excreta in this system are an additional source of nutrients to the soil (Mambir et al., 2018). The challenge of finding consistent results is that residue grazing effects can vary according to the animal class, length of the grazing season, grazing strategy, climate, and topography (Weesies et al., 1994). Therefore, it is crucial to understand the impact of finishing heifers grazing snaplage residue under tropical conditions in an integrated system. Thus, we hypothesize that grazing corn residues may not affect the physical characteristics and improve the chemical characteristics of the soil, consequently positively affecting subsequent crop yields in an ICLS system. we hypothesized that grazing corn residue may not affect or have positive effects on subsequent crop yield in an ICLS system. The objectives were to determine 1) the impact of grazing the residues on the soil physical and chemical properties, 2) the impact of grazing on subsequent crop yield.

2.0 | MATERIALS AND METHODS

The experimental procedures of this study were approved by the Ethics and Animal Welfare Committee of the Federal University of Lavras (protocol number 008/2019).

2.1 | Experimental Site

The experiment was carried out at the Experimental Farm at Federal University of Lavras, Brazil (21°14′09” S, 45°58’35” W; 880m above sea level). This area has a subtropical humid mesothermal climate with dry winters (Köppen-Geiger climate classification: Cwa; Sá Júnior et al., 2012). Meteorological data were obtained from a weather station located 1,000 m from the experimental area (Figure 1). The soil (0 – 0.20 m) had the following properties: pH (H_2O) = 5.5; exchangeable Al, Ca, Mg; 0.1, 1.7 and 0.3 cmolc/dm^3, respectively; available P (Mehlich-I method) 2.2 mg/dm^3, exchangeable K 34.9 mg/dm^3 and organic matter 17.0 g/kg

The experiment was carried out during 20 months (from August 2018 to February 2020). It was divided into three phases: the first phase was the production of the corn crop (snaplage production), in which the corn residue was used for animal finishing, the second consisted of the animals finishing in this area (animal production), and the third consisted of evaluating the impact of grazing on subsequent corn crop yield.

2.2 | Corn crop establishment and soil inputs

The corn was planted on October 29, 2018, following agro-climatic zones of the corn crop according to the classification of the chosen hybrid. The population density used was 70,000 plants per hectare. A simple Pioneer corn hybrid (LG-3055) of an early cycle was planted, which is recommended for the time and place where the experiment was performed. Corn crops were planted with the application of 300 kg/ha of pre-formulated fertilizer (08:28:16 of N:P:K) based on soil nutrient requirements. The first maintenance fertilization was applied when the plants had developed the fourth expanded leaf (19 days after planting) and it was applied at 100 kg/ha of NPK 30:00:20. The second maintenance fertilization was applied at 32 days after planting with the application of 100 kg/ha of NPK 30:00:20 when the plants developed the sixth expanded leaf.

After 29 days post-planting, the crop treatments were performed using post-emergent herbicide Atrazine (*Albaugh*®*; 4 L/ha*), and Tembrotriona (*Soberan*®*; 0.2 L/ha*), for broad and narrow leaves, and an insecticide immunity (BASF®*;* 0.2 L/ha). During the entire cycle of the crop, monitoring was performed to observe the presence of pests, especially the cartridge caterpillar, fungal diseases, and the possibility of atypical weather conditions.

2.3 | Treatments and Experimental Management

The corn crop was harvested 132 days after planting for snaplage. Immediately after the corn harvest, the area was divided into twenty-four paddocks and the treatments were randomly allocated. The treatments were two stocking rates (SR) in the animal unit (AU; the animal unit was considered a bovine weighing 500 kg; (Allen et al., 2011), namely: (1) **Low stocking rate (LS; 3.5 AU/ha**, (2) **High stocking rate (HS; 7.0 AU/ha)**, and an ungrazed treatment namely: (3) **Ungrazed (CT; Control)**. The treatments were obtained by modifying the size of the paddocks. The LS, HS, and CT paddocks size had 6,000, 3,000, and 2,000 m^2, respectively.

Forty-eight F1 crossbred heifers (Angus x Nellore; 276 ± 20 kg of body weight [BW] and 16 ± 1.3 months of age) were used as tester animals, with three animals in each paddock. The animals were identified, weighed, treated against internal and external parasites, and housed in a pasture with proper forage allowance and available water until the corn snaplage harvest. Immediately after the corn snaplage harvest, the animals entered the experimental area. The experimental grazing period was 96 days.

2.4 | Experimental evaluations

2.4.1 | Corn residue mass

Snaplage residue mass was sampled by harvesting three frames at ground level, measuring 1.5 x 1.4 m per paddock, at sites randomly selected. The residue mass was collected after corn was harvested for snaplage for characterization and quantification of the initial corn residue mass in each paddock, on the final day of grazing period (day 96; animal production) to quantify the residue that remained in the area, and seven days before planting the subsequent crop for characterization and quantification of pre-planting residue. The corn residue samples were separated into residue and contamination (weeds + grass). The samples were oven-dried at 55°C for 72 h to a constant weight.

2.4. 2 | Soil chemical analysis

Twenty random soil subsamples were collected from each experimental unit (paddock) totaling Twenty-four samples (1 per paddock) in the 0-20 cm layers for chemical analysis before subsequent crop planting. The analyses performed were pH in H_20, calcium (Ca), magnesium (Mg), potential acidity (H+Al), potassium (K) and phosphorus (P) according to Embrapa (2017). The exchangeable sum of basis (SB), cation exchange capacity (T) in pH 7.0, and soil base saturation index (V) were then calculated.

2.4.3 | Nitrogen balance

The N return to the system was obtained by analyzing the snaplage residue and fecal samples for N concentration according to method 920.87 (AOAC, 2000). To determine fecal N excretion (FNE), fecal production was multiplied by the total N concentration in the feces. Urinary N excretion (UNE) was calculated using the NRC, (2016) equation (Eq. 16-1):

$$\text{Urine N} = 2.39\ (\pm 4.05) + 0.55\ (\pm 0.03)\ \text{N intake} - 3.36\ (\pm 0.03)\ \text{DMI}$$

Where Urine N is urinary N excretion (g/d), N intake is N intake (g/d), DMI is dry matter intake (kg/d).

The N content returning via residue (N residue) was estimated using the residue disappearance. For this purpose, the pre-planting mass and residue intake were removed from the initial mass. The amount of disappeared residue was multiplied by the N content of the residue.

2.4.4 Soil aggregates stability

Three undisturbed soil blocks were collected from each experimental unit at 0-0.1m depth. The samples were gently handled into smaller aggregates (keeping the original structure), passed through a 7.9 mm diameter sieve, and retained in a 4.76 mm sieve. Aggregate stability was determined according to Kemper and Chepil, (1965) . Using a Yoder-type apparatus, aggregates were water-sieved in 2, 1, 0.5, 0.25, and 0.105 mm for fifteen minutes. The mass of the material retained on each sieve was placed in an oven at 105^{o}C. The results were expressed as a percentage of the aggregates retained on sieves >0.25 mm (macro-aggregates) and <0.25 mm (micro-aggregates), geometric mean diameter (GMD), and mean weight diameter (MWD).

2.4.5 Soil physical-hydrical analysis

Seventy-two undisturbed soil samples, tree for each paddock, were collected at 0 - 0.05m depth using metallic cylinders. In laboratory, samples were saturated and placed on an automated tension table (EcoTech, Germany), being drained to matric potentials of

–1, –2, –4, –6, and –10 kPa. The samples were than drained to matric potentials of -33, -100, -500, and -1500 kPa in a Richards porous plate chamber (Klute, 1986).(Klute, 1986). Dry mass was obtained in oven (105-110ºC). Bulk density (Bd) was determined using core method (Grossman and Reinsch, 2002). Particle density (Pd) was obtained by the volumetric flask method (Flint and Flint, 2002). Thus, total porosity (Tpc) was calculated by the following equation: Tp= [1 – (Bd/Pd))]. Total porosity was also determined (Tpd) using water content at saturation (water-filled pores). Microporosity was calculated using matric potential of -6 kPa (pore diameter < 0,05 mm). Macroporosity was obtained by difference between Tpc and Microporosity. Water content at field capacity was calculated using matric potential of -10kPa. Aeration capacity and relative field capacity were calculated as described by (Reynolds et al., 2009, 2002)

2.4.6 Penetration resistance (PR)

Penetration resistance (PR) was evaluated by laboratory, and field methods. In the laboratory, the undisturbed soil samples obtained as described previously, were drained at -10 kPa matric potential in an automatic tension table to achieve water content at field capacity. After reaching equilibrium, each sample was weighed and subsequently, its PR was determined by the bench penetrometer (Tormena et al., 1998). The penetrometer used (Marconi, model MA 933, Brazil) has a cone tip (45° angle and 0.00384 m diameter) running at a constant velocity of 0.01 m/min. Applied force (kgf) was converted to PR (MPa) by the following equation adapted from Serafim et al. (2013):

$$PR=Mg / (\pi r2 / \cos45°) \times 1/106;$$

where: PR is the soil penetration resistance in MPa; M is the mass of the apparatus (kg); g is the gravitational acceleration (9.806648 m s−2); π is 3.1415926 (dimensionless); r is the straight circular cone radius (0.00192 m); and the 45° cosine of the cone surface angle, which is 0.7071.

In the field, three samples were collected per plot totaling 72 points at a depth of 0-10, 10-20, 20-30, and 30-40 cm, assessed by a dynamic/impact penetrometer (IAA/Planalsucar Stolf model, Kamaq, Brazil). This penetrometer consists of an impact weight (4kg mass), a rod (curse of free fall of 0.4 m), and a ground-penetrating cone. PR (MPa) was calculated through the equation proposed by (Stolf, 1991), as following:

$$PR = (Mgh / Ax)\, M / (M + m) + ((M + m) / A)\, g,$$

where: M / (M + m) is the fraction of energy remaining minus impact losses; M (kg) is the mass of 4 kg; m (kg) is the mass of the penetrometer; A (m^2) is the cone base area; and g ($m\ s^{-2}$) the gravitational acceleration.

Undisturbed samples were also used for soil water content determination using the thermogravimetric method in twenty points distributed in the experimental area in the layer from 0 to 10 cm.

2.4.7 | Planting the subsequent crop

The crop establishment start with fences removal to ensure uniform planting throughout the experimental area. The area was chemically terminated five days before planting by applying Glyphosate (*Round-up®; 5 L/ha)*. The planting was performed on October 19, 2019, using the no-tillage technique. A simple early cycle corn hybrid (LG-3055) was planted, which is recommended for the season and location where the experiment was conducted. The corn crops were planted with the application of 38.6 kg/ha of N, 135 kg/ha of P_2O_5, and 77.2 kg/ha of K_2O by applying the pre-formulated fertilizer (08:28:16 of N:P:K) based on the soil nutrient requirements. The first and second maintenance fertilization, crop treatments, and management were performed similarly to the first crop.

2.4.8 | Harvest and subsequent yield evaluation

The harvest was carried out on February 19, 2020, when the crop had an average of 34% dry matter. To calculate yields, four random points were chosen per paddock. At each site, three linear meters of plants were cut by hand at 25cm above the ground. Afterward, row spacing and the number of plants in 3m were determined (Lima et al., 2022). The plants of each row were bundled and weighed using a digital scale (HDI 2100; HOMIS BRASIL). Half of the total plants from each site chosen to be chopped forage were divided into two subsamples. The first subsample was dried at 55°C for 72h in a forced-air oven to assess DM and the second subsample was frozen. The other half of the plants was divided into leaves (leaf sheath and leaf blade), stem, and ear. The ears were split into cob, husk, and grain (Verbič et al., 1995), to determine the proportion of each component. Row spacing, number of plants in 3 m, and plant weight were used to estimate total fresh yield and plant population per hectare. The DM content of each component was used to estimate total mass (kg/ha), vegetative components mass (kg/ha) (stem+ leaves yields), and ear mass (kg/ha) (cob+husk+grain yields).

2.5 | Statistical analysis

The experiment was carried out in a completely randomized design with three treatments (high stocking rate, low stocking rate, and ungrazed) and eight replications. The initial, final and pre-planting mass variables were analyzed using the PROC MIXED of SAS 9.4 statistical software (SAS Inst. Inc., Cary, NC), considering the paddock as experimental unit. The statistical model for data analysis was calculated as follows:

$$Yij = \mu + SRij + \gamma ij$$

where Yij is the observed measurement in of the ith stocking rate; μ is the overall mean; SRi = fixed effect associated with ijth stocking rate, $j = 1, 2, 3$; γij = random error associated with the ijth SR.

The physical and chemical soil characteristics, total yield dry matter, vegetative components mass, and ear mass were performed by the MIXED procedure of the SAS 9.4 program. The effect of grazing or non-grazing was assessed by the contrast HS and LS (Grazing) versus CT (ungrazed control), whereas the effect of stocking rate was tested by the contrast HS versus LS. Statistical significance was considered at $P \leq 0.05$.

The multivariate analysis technique that consists in transforming a set of original variables into another set of variables of the same dimension called principal components with a minimum loss of information through linear combinations of the original variables. These linear combinations are called principal components and are not correlated among themselves (SANDANIELO, 2008). Multivariate analysis was performed using the biplot PCA, by means of *prcomp* functions from the stats package (R Core Team, 2018), *ggbiplot* (Vu, 2011), *vegan* (Oksanen et al., 2018), *tidyverse* (Wickham, 2017), and *devtools* packages (Wickham and Chang, 2016). In addition, a standardization of each variable was performed due to the variables presented different dimensions. The data of residual mass, soil physical properties (soil density, macroporosity, penetration resistance at field capacity, weighted mean diameter), soil chemical composition (pH in soil, phosphor, potassium, animal nitrogen, residue nitrogen, sum of bases, cation exchange capacity, soil base saturation), and subsequent crop yield (total yield dry matter, vegetative components mass, Ear mass) were plotted against the stocking rates (high stocking rate, low stocking rate, ungrazed control) to characterize the variability of the data set and its behavior in relation to the evaluated treatments. Correlations were obtained using the 17-variable dataset. Algebraically, the principal components represented linear combinations of p random variables $X1$, $X2,\cdots,Xp$, in which $p = 17$. In addition, as the variables presented different dimensions, a standardization of each variable was performed.

3.0 | RESULTS

3.1 Residue mass

The initial residue mass was similar among treatments ($P \leq 0.98$; Figure 2) with a mean of 9,600 kg of DM/ha. However, the HS paddocks (5,162 kg of DM/ha) had reduced ($P = 0.01$) final mass compared with CT (7,011 kg of DM/ha) and LS (6,434 kg of DM/ha) was intermediate and not different from either.

3.2 Pre-planting mass

The CT treatment had the greatest ($P < 0.01$; Figure 3) total pre-planting mass (10,599 kg of DM/ha) than the LS and HS treatment (7,122 and 5,178 kg of DM/ha, respectively). There were also differences ($P < 0.01$) for residue pre-planting mass with CT (5,734 kg of DM/ha) having greater mass than HS treatment (3,582 kg of DM/ha) but both were not different than LS treatment (4,481 kg of DM/ha). The CT and LS had a greater ($P < 0.01$) weed pre-planting mass (1937 and 1712 kg of DM/ha, respectively) than the HS pasture (899 kg of DM/ha, HS decreased by 53% of the weed incidence compared to CT, and 51% compared to LS).

There were differences detected ($P < 0.01$) among treatments for pre-planting grass mass; CT had greater mass (2,998 kg of DM/ha) compared to LS and HS (929 and 696 kg of DM/ha, respectively). The presence of animals decreased grass mass by 2,100 kg of DM/ha compared to CT treatment.

3.3 Soil physical analyses

The soil aggregates stability data are presented in Table 1. No grazing or stocking rate effects were detected ($P \geq 0.35$) Likewise, there were no effects for macro and micro-aggregate between stocking rates. However, a tendency ($P = 0.07$) was observed for macro-aggregate which was greater for the ungrazed treatments and micro-aggregate was greater ($P = 0.07$) for the grazed treatments.

The PR data are presented in Table 2. No grazing or stocking rate effects were detected ($P \geq 0.22$) for PR in the four depths evaluated. Furthermore, there was no effect detected ($P = 0.85$) for moisture between stocking rates.

3.4 Soil chemical analyses

N variables are presented in Table 3. The urinary N excretion, fecal N excretion, and total N excretion were increased with grazing (*P* < 0.01). However, N variables were not affected by stocking rate (*P* ≥ 0.85). There were grazing effects (*P* < 0.01) for urinary N excretion total, fecal N excretion total, and animal N excretion total. There were also differences in stocking rate (HS > LS; *P* < 0.01) with HS having 50% more excretion than LS.

There was an effect of grazing (*P = 0.02*) for N return via residue. Grazing increased return by 37% compared to the ungrazed treatment. However, there were no differences (*P* = 0.45) between stocking rates.

The total nitrogen balance was increased by grazing (82% compared to ungrazed; *P* < 0.01). In addition, a stocking rate effect was observed (LS < HS; P = 0.01), with HS having 40% more N returned than LS.

The macronutrients P and K were also increased with grazing. The concentrations of K increased by 28% compared to the ungrazed (107 vs. 77.4). However, the K concentration was not affected by the stocking rate (*P* = 0.55). The P concentration increased 42% with grazing (*P* = 0.02). Additionally, HS increased P concentration by 43% compared to LS (*P* = 0.01). Grazing resulted in a 5% decrease (P < 0.01) in pH compared to ungrazed (5.8 vs. 5.5). Furthermore, a stocking rate effect (*P* = 0.05) was observed. The LS was 4% greater than HS (5.6 vs 5.4).

The calcium (Ca) and magnesium (Mg) concentrations were similar within grazing and the stocking rate evaluated (P ≥ 0.73).

3.5 Subsequent Crop Yield

The grazing positively affected all the parameters of productivity of the subsequent crop (Table 4). The total yield mass, vegetative components mass, and ear mass were increased by grazing (15, 17, and 13%, respectively, compared to ungrazed; *P* ≤ 0.04). However, there were no differences (*P* ≥ 0.83) between stocking rates.

3.6 Relationship among response variables

The PC1 and PC2 explained 29.4 and 23.6 % of the variability in the dataset, respectively. The data for RM and pH are associated with the ungrazed paddock. being found higher values of these variables in the CT treatment. The data for animal N, residue N, , and P were more are associated with the HS treatment, indicating higher values for these attributes. The data of total yield of dry matter, vegetative components mass, and ear mass, although closer to the high stocking rate treatment, were also associated with low stocking rate, showing that grazing was enough to increase productivity. In addition, the parameters of soil density, macroporosity, penetration resistance at field capacity, and weighted mean diameter are not associated with the grazing, these variables are an indication that grazing did not affect the physical characteristics of the soil.

4.0 | DISCUSSION

The overall effectiveness of the integrated crop-livestock system is improved through advancements in each of the sectors, including soil preservation and enrichment. This can lead to increased productivity of each element or a reduction in production costs. Due to their intricate connection, it is not easy to analyze the effect of each component individually (Balbino et al., 2012). In the current study, each factor involved will be discussed separately showing the interrelationships and impacts on subsequent crop yield. The first is the removal of residue. In high yielding crops, often an abundant amount of residue remains in the field which leads to subsequent yield declines by depressing subsequent grain yields (Karlen et al., 2014). (Karlen et al., (2014) showed that removal of 46 to 85% residue, which they called moderate and high removal respectively, led to increase of corn yields in 57 and 51% of the sites evaluated, respectively. In this experiment, the reduction was 63 and 53% of residue for HS and LS respectively. This residue reduction includes the removal by animal and weathering. In the CT, this reduction was 40%. Therefore, the grazing of the animals in the current experiment resulted in a removal within the average reported by these authors.

The similarity in initial residue mass among treatments can be explained by the fact that the same area was used with corn crop under the same conditions and only divided into paddocks. The climatic conditions favor the disappearance of the residue (Lehman et al., 2021). It is noted in Figure 1 that the amount of rainfall was above average in the first weeks of the experimental period. Furthermore, intake and trampling increased the residue disappearance in grazing treatments (Lehman et al., 2021; Parr and Papendick, 2015; Ward, 1978). The residue intake is characterized by selectivity, as the animals search for the more digestible components such as leaves and husks. Consequently, this search increases trampling. (Fernandez-Rivera and Klopfenstein, 1989b; Gutierrez-Ornelas and Klopfenstein, 1991; Lehman et al., 2021; Stalker et al., 2015). Thus, when using high stocking rates, this effect is amplified.

From the end of the experimental grazing period (animal production) until the beginning of the planting of the subsequent crop, the residue mass continued to disappear (Figure 3b) due to the degradation process of this material (Lamm and Ward, 1981). However, in the grazed treatments, the disappearance was greastest. Grazing resulted in a reduction of 30% of the pre-planting mass compared to the final mass, while in the CT this reduction was 18%. The trampling can increase the crushing and consequently the exposure of the material to degradation agents, by modifying the physical structure of the residue. The crushing of the residue into smaller particles increases the surface contact for microorganisms' action, increasing the decomposition of this material and, consequently, the mineralization of these nutrients (Rakkar and Blanco-Canqui, 2018b)

The HS affected the reduction of weeds in the area (figure 3c) due to the high density that intensified trampling and grazing (Sulc and Tracy, 2007)and decreases the seed bank of these types of weeds. This response was observed by (Reintam and Kuht, 2012), who found a reduction in the seed bank in barley fields due to trampling by animals. The weeds are trampled and killed by the animals in the germination and development, thus reducing their prevalence. The current experiment observed a 53% reduction in weeds when comparing the HS treatment with the CT. The same can be considered when analyzing the appearance of grass in the area (figure 3d). Depending on the objective of the production system, the grass can be viewed as a weed since its presence causes negative interference in the main crop. In the current experiment, the effect of residue grazing on the incidence of grass was observed in both stocking densities. This is explained by animals grazing and trampling these plants when they emerge, thus preventing their development. Without animal interference in the ungrazed treatment, these plants continued to grow. Grazing and increasing the stocking rate is a strategy to control weeds in the planting area of the subsequent crop, thus reducing the cost and need of herbicides to control weeds

The effect of grazing crop residues on soil properties is a major concern of farmers when adopting ICLS since the presence of animals can promote soil compaction. Our results showed no effect on the soil physical characteristics of bulk density and soil penetration resistance, comparing the grazed (HS and LS) with ungrazed treatments (CT). Soil bulk density values were below the limit root growth according USDA, (2008), which considers values above 1.47 Mg/m^3 for clayey soils and 1.80 Mg/cm^3 for sandy soils. For Brazilian soils, based on the findings of Reichert et al. (2003) the critical soil density ranges from 1.30 to 1.40 Mg/m^3 for clayey soils, 1.40 to 1.50 Mg/m^3 for clayey loamy soils, 1.40 to 1.50 Mg m-3 for clayey loamy soils, and 1.25 to 1.25 Mg m-3 for clayey clayey soils, 1.40 to 1.50 Mg m-3 for clayey loamy soils and 1.70 to 1.80 Mg/m^3 for sandy loam soils. In the current experiment, the values averaged was 1.14 Mg/cm^3. The penetration resistance was not affected (Table 3), and similarity between grazed (HS and LS) and ungrazed (CT) treatments was observed. Although cattle have great compaction power depending on their age and weight, with a pressure that varies from 98 to 192 kPa (Taboada et al., 1999) whereas a tractor has an average of 27 to 68 kPa (Rakkar and Blanco-Canqui, 2018). In the current experiment the PR data showed that there was no compaction in the evaluated treatments, especially in the 0-10 cm layer where any compaction by grazing animals can occur (Bell et al., 2011; Greenwood and McKenzie, 2001). However, the evaluated treatments averaged 2.60 Mpa. This value is lower than that of (Moraes et al., 2014), which considers values above 3 MPa and 3.5 Mpa for minimum tillage with chiseling and no-tillage, respectively.

No effect on soil physical characteristics can be explained by the stocking rate used, season of the year and possible positive effect on soil aggregates. In the current experiment, the HS treatment (7.0 AU (500kg)/ha or 8.3 AU (450kg)/ha) was below the minimum to cause any damage to soil aggregates, which is 9.3 - 13 AU(450kg)/ha (Rakkar et al., 2017). The season in which the animals grazed the residue in the current experiment was predominantly dry (Figure 1). Cattle feces can increase the concentration of organic matter in soil (Maillard and Angers, 2014; Schlegel et al., 2015). By (Greenwood and McKenzie, 2001)(Maillard and Angers, 2014; Schlegel et al., 2015). By having lower density, organic matter can increase the elasticity of the soil matrix (Blanco-Canqui et al., 2015; Soane, 1990). Thus, grazing did not affect the physical characteristics of the soil or promoted a positive effect on this variable.

Corn residue grazing increases the N and C and minerals levels in the soil through animal feces and urine when animals were supplemented (Drewnoski et al., 2016; Maughan et al., 2009). In the current experiment, grazing increased N concentrations compared to the ungrazed treatment, HS and LS treatments added an equivalent of 100 and 50 kg of N/ha respectively, only from the animal, in addition to this an increase in the return by residue decomposition was observed for previously mentioned factors. The increase in N may have been one of the factors that contributed to subsequent yield increase. Studies indicate that adding N leads to increased grain yield by affecting grain weight, the number of kernels per ear, consequently ear weight, and protein concentration (Wei et al., 2019). In Brazil, when farmers want to increase yields, high nitrogen application is a widely used technique because Brazilian soils have low N content and consequently a high C: N ratio. This is especially true when there are crop residues in the soil, which have a C:N ratio ranging from 26 to 82:1 (Rakkar and Blanco-Canqui, 2018b).

Grazing in addition to concentrated feed increased the input of K and P in the crop system. Although the removal of these nutrients is greater with grazing residue by animals, a large amount of these nutrients returns to the system via feces (Rakkar et al., 2017). However, many places have concerns about the levels of P in the soil mainly when applied in large quantities (Hilimire, 2011; Russelle et al., 2007a). In Brazil, most soils are poor in P and K, increasing the content of these nutrients through the use of integration can be an essential tool to increase productivity as shown in the data of the current experiment.

The difference in soil pH with grazing can be explained by the deposition of feces and urine by the animals, which was higher in the HS treatment when compared to the LS. The decomposition of the organic matter present in the excreta by soil microorganisms' releases ammonia (NH3) which turns to nitrate releasing H+. Since one of the processes of soil acidification is the accumulation of organic matter and a and a consequent increase in CEC and acidity exchange (Haynes, 1983). Although not directly evaluated the organic matter content, in the grazed treatments could increase due to animal excretion and higher residue decomposition.

In addition, the urea present in the animals' urine releases H+ by reacting the NH_4 with the soil. H+ ions in the soil, in turn, favor soil acidification (Meurer et al., 2010). Although the decrease in pH content is statistically different, the difference was not enough to cause any agronomic impact on the subsequent crop due to the proximity of the values. In the current experiment, the addition of animals to the system increased the subsequent crop yield (Table 4). Grazing affected parameters cited above such as nutrient return and residue removal that impact yield increase. However, increasing stocking rate did not affect subsequent yield, although an increase in the parameters cited was observed in HS when compared to LS. The vegetative components and ear mass followed the same pattern as the total yield mass when comparing the grazing or stocking rate evaluated. As cited by (Lima et al., 2022) there is a high correlation between these two components with total dry matter production, being a good indicator of productivity.

The productivity increase of the crop and animal components in ILCS systems is a result of the interaction of several factors and is often difficult to separate this justifies why the PCA approach was used, since it allows understanding the correlation of all the analyzed variables and their correlations, whether positive or negative. Thus, it is possible to observe the correlation between them in figure 4, analyzing the combination of all these elements allows us to understand the dynamics of each component within the system and to explain the increase in productivity of the subsequent crop in the current experiment. The factors that positively affect production are positively correlated with grazing. Among these factors, the return of macronutrients such as N and P increased when the residue was grazed with a positive correlation with yield parameters independent of the stocking rate evaluated. A positive correlation among stocking rate, animal nitrogen, residue N, K, P, total yield of dry matter, mass of vegetative components, and ear mass suggests that the presence of animals grazing the residue increases the subsequent crop yield. Also, this may indicate a high correlation with the increase in the stocking rate.

The other parameters of soil chemistry and physics involved in the analysis were not correlated to the evaluated treatments. The absence of correlation with grazing in these parameters suggests that they did not affect subsequent production. In addition, only the residual mass and pH were related to the non-grazed treatment for factors that have already been mentioned above.

In ICLS aimed at optimizing land use, the reduction of inorganic fertilizer input can be an interesting strategy. Although it has some nutrients, animal excreta cannot reach the amount of nutrients that a crop needs, either because of low density (Gupta et al., 2012) or because of its localized application. Based on the results of the current experiment an alternative would be the combination of both sources (chemical and organic) reducing the cost of fertilizer acquisition, thus having an economic and sustainable impact as it reduces the negative effects of fertilization on the soil (Sabir et al., 2021).

Economically profitable food production requires combining the highest productivity with efficient resource use (Chandini et al., 2019). The use of residue grazing in the current experiment has shown to be an excellent tool, since it was possible to integrate two corn crops with beef cattle finishing, maximizing the use of land during the fallow period between crops. In several places, there are reports of income increases with the use of ICLS, reducing the vulnerability of these production systems to climatic events or market (Peyraud et al., 2014; Russelle et al., 2007a). Moreover, the reduction in production costs through complementarities between crop and livestock, or likely reduction in the amount of fertilizer and herbicides decreases dependence on factors beyond the control of the producer.

5.0 | CONCLUSION

The use of the residue for cattle finishing is a viable strategy utilized in the ICLS. Grazing residue had no negative effects on the physical characteristics of the soil while increasing concentrations of macronutrients such as nitrogen and phosphorus from animal supplementation. This data indicates that grazing residue positively affected the subsequent corn yield. Grazing snaplage residue as a roughage source allow adding beef production between two corn crops without negatively affecting production of the next crop.

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TABLES AND FIGURES

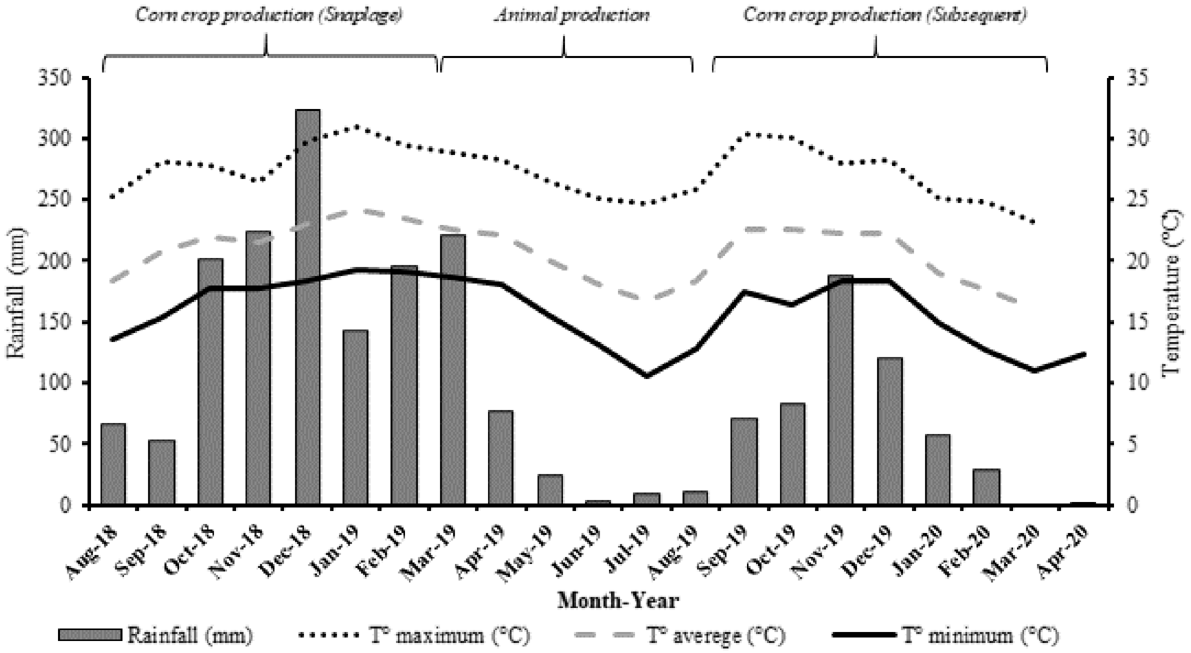

Figure 1. Mean monthly temperatures and rainfall in Lavras, Brazil, during the experimental period

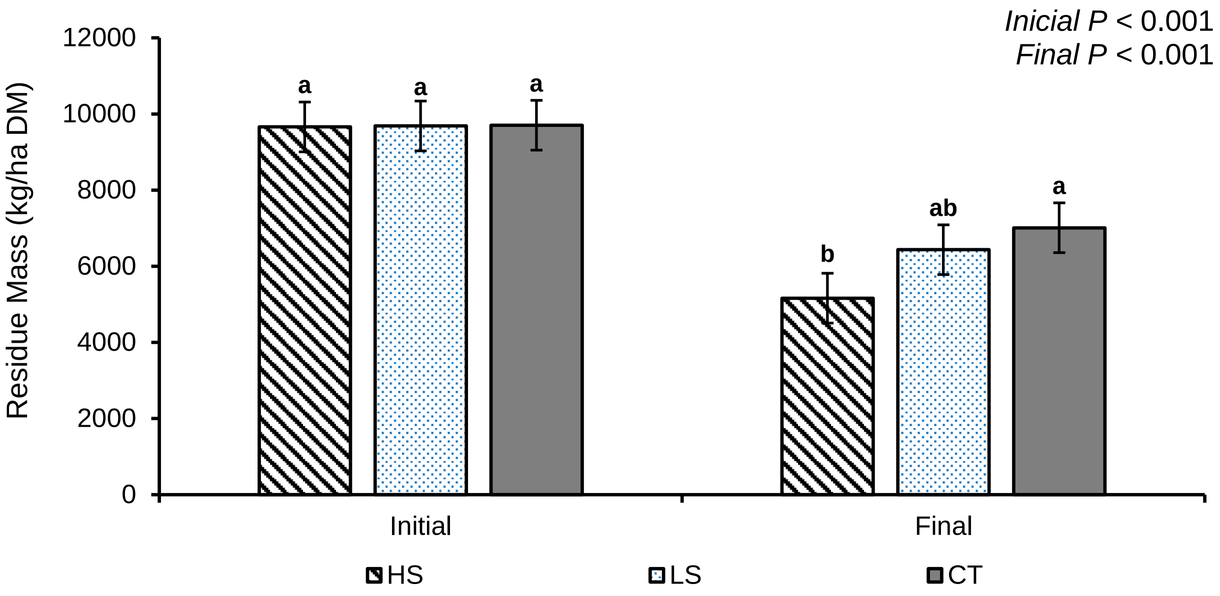

Figure 2. Effects of grazing and stocking rate on initial (prior to grazing) and final (post grazing) residue mass. HS = high stocking rate; LS = low stocking rate; CT = ungrazed control. Means with a common letter (a, b) do not differ statistically ($P \leq 0.05$). Error bars represent the SEM.

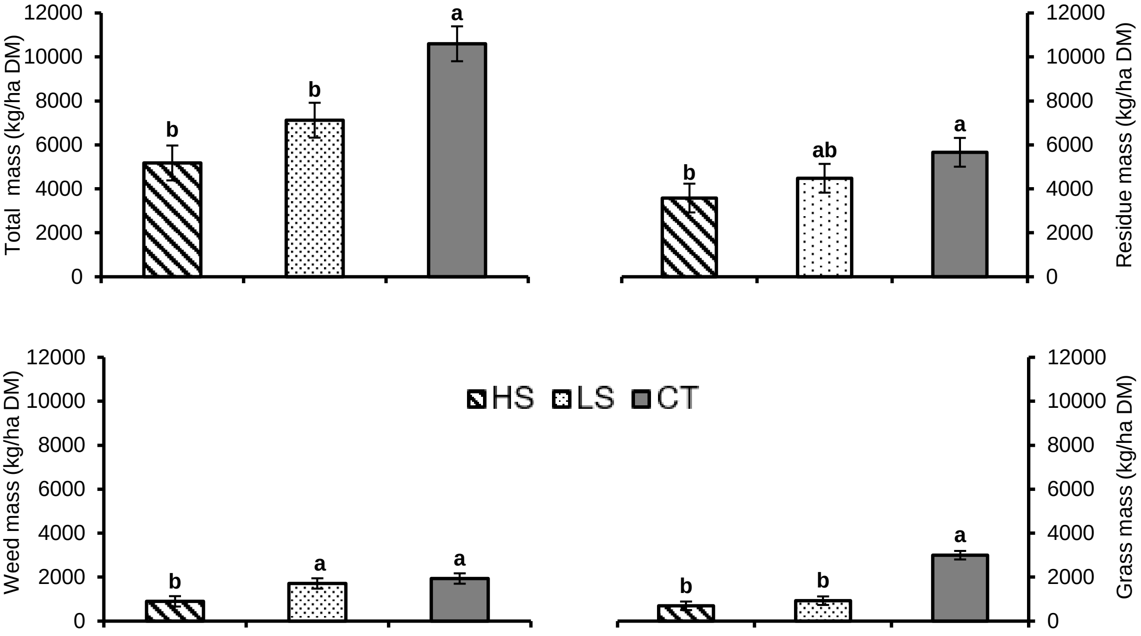

Figure 3 Effects of grazing and stocking rate on initial (prior to grazing) and final (prior to planting subsequent crop) residue mass. HS = high stocking rate; LS = low stocking rate; CT = ungrazed control. Means with a common letter (a, b) do not differ statistically ($P \leq 0.05$). Error bars represent the SEM.

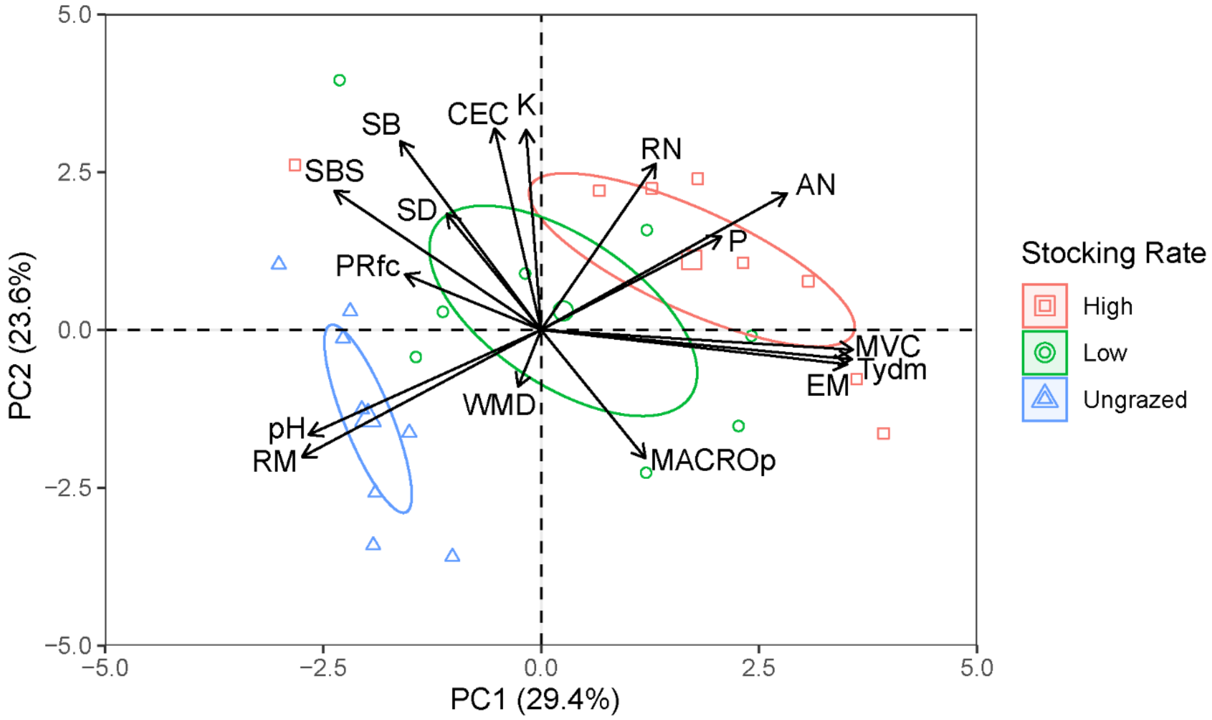

Figure 4. Biplot principal components analyses High: High stocking rate; Low: low stocking rate; Ungrazed: ungrazed control; RM: residual mass; SD: soil density; MACROp: macroporosity; PRfc: penetration resistance at field capacity; WMD: weighted mean diameter; pH: soil pH; P: phosphor; K: potassium; AN: animal nitrogen; RN: residue nitrogen; SB: sum of bases, T: cation exchange capacity; V: soil base saturation; TYdm: total yield dry matter; MVC: mass of vegetative components; EM: ear mass.

Table 1. Effects of grazing and stocking rate on physical analysis of the soil aggregate of the Snaplage residue

Item	**Treatments**[b]			**SEM**[a]	***p-value***	***P-value* contrasts**	
	HS	**LS**	**CT**			***Grazing***	***Stocking***
Mean geometric diameter (mm)	2.16	2.09	2.23	0.10	0.59	0.38	0.60
Weighted mean diameter (mm)	2.70	2.68	2.74	0.07	0.82	0.57	0.80
Macro-aggregate	96.0	95.4	96.7	0.41	0.13	0.07	0.35
Micro-aggregate	3.93	4.93	3.25	0.41	0.13	0.07	0.35

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha), CT (Ungrazed control)

Contrasts: Grazing (CT versus HS+LS), Stocking rate (HS versus LS).

Table 2. Effects of grazing and stocking rate on physical analysis of the soil penetration resistance of the snaplage residue

Item	**Treatments**[a]			**SEM**[b]	***p-value***	***P-value* contrasts**	
	HS	**LS**	**CT**			***Grazing***	***Stocking***
Soil depth (cm)							
0-10	2.42	2.74	2.66	0.44	0.86	0.89	0.60
10-20	2.63	3.02	3.16	0.24	0.29	0.27	0.25
20-30	3.17	3.45	3.19	0.12	0.22	0.44	0.12
30-40	3.24	3.60	3.20	0.21	0.37	0.42	0.25

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha), CT (Ungrazed control)

Contrasts: Grazing (CT versus HS+LS), Stocking rate (HS versus LS).

Table 3. Effects of grazing and stocking rate on nitrogen balance and soil chemical analysis at a depth of 0 – 20 cm of the snaplage residue

Item	**Treatments[b]**			**SEM[a]**	***p-value***	***P-value* contrasts**	
	HS	**LS**	**CT**			***Grazing***	***Stocking***
Nitrogen (N)							
Animal							
UNE, g of N/day	67.0	67.1	0	1.76	<0.01	<0.01	0.85
FNE, g of N/day	38.7	39.8	0	2.75	<0.01	<0.01	0.90
TNE, g of N/day	105	106	0	3.36	<0.01	<0.01	0.92
Unit of area							
UNE, kg of N\ha	64.3	32.4	0	1.91	<0.01	<0.01	<0.01
FNE, kg of N\ha	37.2	19.1	0	2.21	<0.01	<0.01	<0.01
N Animal, kg of N\ha	101	51.5	0	3.37	<0.01	<0.01	<0.01
Residue							
N Residue, kg of N\ha	37.8	33.1	22.1	4.33	0.05	0.02	0.45
Nitrogen Balance							
TNR, kg of N\ha	138	84.6	22.1	5.13	<0.01	<0.01	<0.01
Potassium (K)	111	104	77.4	8.46	0.03	0.01	0.55
Phosphorus (P)	4.05	2.30	1.84	0.45	<0.01	0.02	0.01
Calcium (Ca)	2.60	2.69	2.70	0.18	0.91	0.81	0.73
Magnesium (Mg)	0.84	0.83	0.82	0.06	0.98	0.85	0.94
pH	5.40	5.60	5.80	0.06	<0.01	<0.01	0.05

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha), CT (Ungrazed control)

Abbreviations: FNE, feces nitrogen excretion; *SEM*, standard error of the means; TNE, Total nitrogen excretion; TNR, Total nitrogen returning; UNE, urinary nitrogen excretion.

Contrasts: Grazing (CT versus HS+LS), Stocking rate (HS versus LS).

TNR = N animal (kg of N\ha) + N residue (kg of N\ha)

Table 4. Effects of grazing and stocking rate on total mass yield, vegetative components mass, ear of the snaplage

Item	**Treatments**[b]			**SEM**[a]	***p-value***	***P-value* contrasts**	
	HS	**LS**	**CT**			***Grazing***	***Stocking***
Total mass yield (kg de DM.ha^{-1})	33,180	32,910	28,160	1.73	0.09	0.03	0.91
Vegetative C. mass (kg de DM.ha^{-1})	10,780	10,850	8,970	0.61	0.07	0.02	0.93
Ear mass (kg de DM.ha^{-1})	22,410	22,070	19,360	1.13	0.11	0.04	0.83

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha), CT (Ungrazed control)

Contrasts: Grazing (CT versus HS+LS), Stocking rate (HS versus LS).

SUPPLEMENTARY MATERIAL

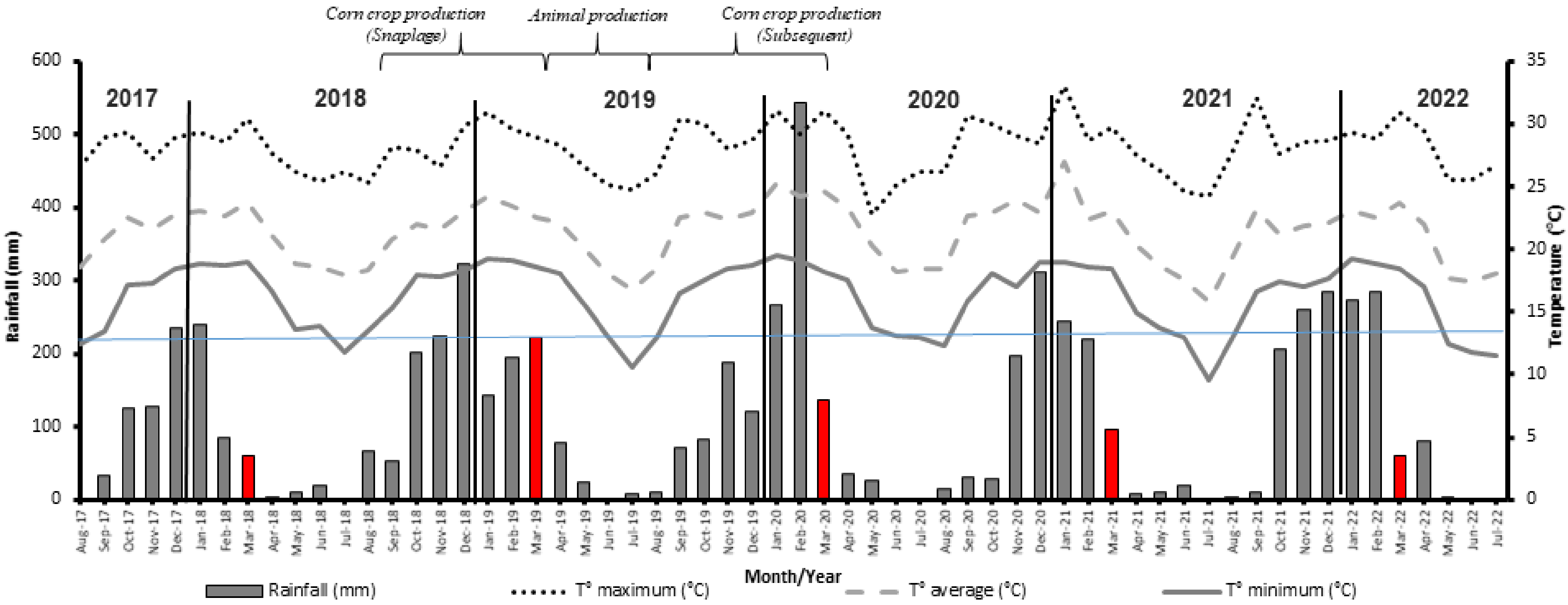

Figure 1. Supplementary. Mean monthly temperatures and rainfall in Lavras, Brazil, 5-year in the experimental period

Table 1 Supplementary. Effects of grazing and stocking rate on physical analysis of the soil rings of the snaplage

Item	**Treatments**[b]			**SEM**[a]	***p-value***	***P-value* contrasts**	
	High	**Low**	**Ungrazed**			***Grazing***	***Stocking***
Bulk density (g/cm³)	1.15	1.13	1.15	0.04	0.93	0.86	0.76
Calculated bulk porosity (m³/m³)	0.562	0.571	0.565	0.01	0.94	0.96	0.73
Microporosity (m³/m³)	0.270	0.283	0.281	0.005	0.20	0.53	0.09
Determined bulk porosity (m³/m³)	0.452	0.461	0.465	0.02	0.93	0.78	0.80
Macroporosity (m³/m³)	0.185	0.177	0.184	0.02	0.96	0.90	0.80
Field capacity (m³/m³)	0.220	0.231	0.230	0.004	0.16	0.44	0.08
Aeration capacity (m³/m³)	0.233	0.230	0.235	0.02	0.98	0.90	0.91
Relative field capacity (m³/m³)	0.495	0.511	0.505	0.02	0.91	0.97	0.67
Penetration resistance at field capacity (MPa)	1.045	1.102	1.434	0.32	0.69	0.40	0.90

[a] SEM: Standard error of means

[b] Treatments: HS (High stocking rate; 7.0 AU/ha), LS (Low stocking rate; 3.5 AU/ha), CT (Ungrazed control)

Contrasts: Grazing (CT versus HS+LS), Stocking rate (HS versus LS)

OVERALL CONCLUSION

The use of snaplage residue for animal finishing (TIR) is an excellent strategy to be utilized in a ICLS. The reduction of the most digestible components occurred at similar rates for both stocking rates evaluated. Using a higher stocking rate (7.0 AU/ha) in the current experiment proved to be an excellent strategy for TIR system, as it did not affect animal performance, leading to an increase in the gain per area. Grazing residue had no negative effect on the physical characteristics of the soil while increasing concentrations of macronutrients such as nitrogen and phosphorus from animal supplementation. This data indicates that grazing positively affected the subsequent corn yield. The TIR system allowed for adding beef production between two corn crops without negatively affecting production in the subsequent crop.

Our results suggest that future studies are needed to evaluate greater stocking rates (>7 AU/ha) in a TIR system. Since, unlike TIP, in TIR the quantity and quality of residues decreases over time, it could be worthwhile to evaluate a step-up concentrate diet to ensure nutritional requirements are met.