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ORIGINAL ARTICLE

Dairy cattle grazing compacts soil surface without reducing subsequent crop yield

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Abstract - Integrated crop-livestock systems are being increasingly used to intensify food production and make it more sustainable. On the other hand, most studies have focused on extensive systems. This paper analyzed the effects of different managements on soil and plants in an intensive integrated system for milk production. An experiment of management systems was installed in southern Brazil, Rio Grande do Sul, on a Latossolo Vermelho (Oxisol), in 2015 to evaluate: rotational grazing of dairy cows in the winter; rotational grazing of dairy cows in winter followed by soil chiseling; and ungrazed area (control). Soil physical properties and yields of crops were evaluated. Trampling by dairy cows increased soil bulk density by 24 % (0.0-0.05 m), but did not influence yields of subsequent soybean or maize. Chiseling reduced the bulk density of the uppermost layer by 19 %, but did not affect the yields of subsequent crops. It was concluded that in years with abundant water, dairy cattle grazing in an integrated crop-livestock system in Southern Brazil compacts the soil surface, but does not compromise the soil physical processes related to the growth and development of subsequent crops.

Keywords: Soil-plant-animal. Cattle trampling. Rotational grazing. Soil chiseling.

O pastejo de vacas leiteiras compacta a superfície do solo sem reduzir a subsequente produtividade de culturas

Resumo - Sistemas integrados de produção agropecuária estão sendo cada vez mais utilizados para intensificar a produção de alimentos e torná-la mais sustentável. Por outro lado, a maioria dos estudos concentrou-se em sistemas extensivos. Este artigo analisou os efeitos de diferentes manejos no solo e nas plantas em um sistema integrado intensivo baseado em produção de leite. Um experimento de sistemas de manejo foi instalado no sul do Brasil, Rio Grande do Sul, em um Latossolo Vermelho, em 2015, para avaliar: pastoreio rotacionado de vacas leiteiras no inverno; pastoreio rotacionado de vacas leiteiras no inverno seguido de escarificação do solo; e área não pastejada (controle). Propriedades físicas do solo e produtividade de culturas foram avaliadas. O pisoteio das vacas leiteiras aumentou 24 % a densidade do solo (0.0-0.05 m), mas não influenciou a produtividade subsequente de soja ou milho. A escarificação do solo diminuiu em 19 % a densidade da camada mais superficial, mas também não afetou a produtividade das culturas subsequentes. Concluímos que em ano com abundância hídrica o pastejo de vacas leiteiras em sistema integrado de produção agropecuária no Sul do Brasil compacta a superfície do solo, mas não compromete processos físicos do solo relacionados ao crescimento e desenvolvimento das culturas subsequentes.

Palavras-chave: Solo-planta-animal. Pisoteio bovino. Pastejo rotativo. Escarificação do solo.

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Introduction

Integrated agriculture has been increasingly used for both intensification of food production and to make the systems more sustainable (FAO, 2010). The integration of livestock and pasture into areas of no-tillage crop cultivation diversifies the production system, increases income, minimizes fallow periods and promotes emerging properties (ANGHINONI *et al.,* 2013; CARVALHO *et al.,* 2010; CARVALHO *et al*., 2018; LEMAIRE *et al.,* 2014; MORAES *et al.,* 2014). However, it is not clear how the different managements affect soil and plants in intensive dairy farming systems.

In extensive grazing systems, animals are left to graze throughout the pasture production season (ALLEN *et al.,* 2011), with low animal density in the area. Thus, although trampling occasionally compacts the soil, the effect is punctual, temporary and generally insufficient to reduce the yield of subsequent grain crops (BELL *et al.,* 2011; CECAGNO *et al.,* 2016; TRACY; ZHANG, 2008). In southern Brazil, there is already a large number of dairy farms where, in addition to pasture, supplementary feed is provided for milk production, but additionally, producers have adopted rotational grazing systems, where a high number of cows graze in short shifts, at high trampling intensity (ALLEN *et al.,* 2011). In this grazing system, animal trampling seems to tend strongly to cause soil structure alterations (KOPPE *et al.,* 2021; LEÃO *et al.,* 2004), but few studies have related these alterations with subsequent crop yields. In other countries, such as New Zealand, concerns about the soil quality in these systems have also been raised (DREWRY, 2006; DREWRY *et al*, 2008; DREWRY and PATON, 2000; DREWRY *et al*, 2004; HOULBROOKE *et al*., 2009).

A better understanding about how integrated crop-livestock systems affect soil and plants could contribute to determine the degree of sustainability of dairy farming in the different regions of dairy expansion in the world. In addition, critical levels of intensification of these systems or strategies that alleviate negative impacts of grazing on soil-mediated processes could be defined. A promising study strategy would be to determine physical properties and hydraulic parameters and monitor soil moisture throughout the crop cycle, in order to relate the soil water tension with the parameters of Feddes *et al*. (1978), to track potential transpiration reduction. In this way, the potential of different management conditions to change the period and level at which soil moisture is beyond the ideal conditions for plants can be determined, taking into account the processes that directly regulate the system productivity (GUBIANI *et al.,* 2018; KAISER *et al.,* 2013).

The overall objective was to study the effects of different management practices on soil and plants in an intensive integrated system for milk production. More specifically, the objective was to analyze (i) whether dairy cattle grazing in these systems compacts the soil surface and reduces subsequent crop yields and (ii) whether soil chiseling after grazing improves soil physical processes related to subsequent crops yields.

Material and Methods

Description

This experiment was initiated in 2015, in the district of São Pedro do Butiá, RS (28º07'35.55"S and 54º51'18.31"W), arranged in a randomized block design with three treatments and four

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replications, and lasted two years. The treatments consisted of: rotational grazing of dairy cows in the winter; rotational grazing of dairy cows in the winter followed by soil chiseling; and ungrazed area (control). In all treatments, soybean and maize were planted in the summer in the experimental plots (17 x 30 m). The soil was classified as Oxisol (SOIL SURVEY STAFF, 2014) and as Latossolo Vermelho (EMBRAPA, 2018), with sand, silt and clay contents of 95, 295 and 610 g kg^{-1}, respectively, in the 0.0-0.20 m layer and the climate as humid subtropical (Cfa). Prior to this study, the experimental area had been used for more than a decade for black oat and ryegrass (*Avena strigosa* + *Lolium multiflorum*) in the winter, for grazing of dairy cows, and for soybean (*Glycine max*) in the summer.

In this experiment, the animals were left to graze in the winter for one day in each block, in a rotational system of oat and ryegrass pasture, in four cycles. Two of three plots of each block were grazed; one of the plots (control) was fenced off from the animals. The stocking density in all plots was 49 animal units (450 kg) ha^{-1}.

Before and after each grazing cycle, the above-ground biomass was quantified. To this end, the biomass of a sample area of 0.25 m^2 per plot was removed from the soil and oven-dried at 60 ºC for 72 h to determine dry weight. The level of defoliation after each grazing was expressed in percentage of reduction in relation to the initial biomass. In addition, before each grazing cycle, gravimetric soil moisture was evaluated in the 0.0-0.10 m layer at one point per plot, using a Dutch auger for sampling. Finally, to complete the database of the conditions preceding each grazing, the soil plasticity limit of the 0.0-0.10 m layer was determined, as proposed by Embrapa (2017). Thus, the gravimetric moisture preceding each grazing was compared with the soil plasticity limit, to indicate the susceptibility to soil compaction at each entry of animals into the plots.

Nine days after the last grazing cycle, the area was completely herbicide-desiccated. Then, one of the grazed plots per block was chiseled with a seven-shank chisel plow. Thirty days after chiseling, the blocks were subdivided to sow soybean and maize with a seeder/fertilizer with furrow openers, in rows spaced 0.45 m apart. Fertilization was applied according to the chemical conditions of the soil (Table 1), for an expected grain yield of 4 Mg ha^{-1} for soybean and 9 Mg ha^{-1} for maize (CQFS, 2016). The dates of the management operations are listed in Fig. 1.

Evaluations

To analyze the impact of management systems on soil and plants, the following parameters were assessed: soil bulk density and pore size distribution; soil hydraulic parameters; soil moisture in the summer crop cycle; and soybean and maize root distribution and yield.

Pore density and distribution were evaluated at three moments: 1 - prior to the installation of the experiment; 2 - after the winter grazing cycles and soil chiseling in the second experimental year; and 3 - after the summer crop of the second year. For this purpose, undisturbed soil samples were collected in stainless steel rings (0.049 m diameter, 0.053 m height) from the layers 0.0-0.05, 0.05-0.10, 0.10-0.20 and 0.20-0.30 m. Two samples per layer were collected from each plot. For the evaluation at the end of the grain crop cycle, one sample was collected within and another in-

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between the plant rows. Finally, pore density and distribution were determined as proposed by Embrapa (2017).

Table 1. Soil chemical properties at the beginning of the experiment, 2015.

Layer (m)	Clay	Loam	Sand	OM	pH water	Ca^{2+}	Mg^{2+}	Al^{3+}	P	K^+
	---------g kg^{-1}---------			%	1:1	---------$cmol_c$ dm^{-3}---------			-----mg dm^{-3}-----	
0.0-0.10	590	300	110	3	5	6.5	2.9	0.4	28.2	216
0.10-0.20	630	290	80	2.3	5.7	7.4	2.9	0	10	120

OM: Organic matter determined by the Walkley Black method; Ca^{2+}, Mg^{2+} and Al^{3+} extracted with KCl (1 mol L^{-1}); Ca^{2+} and Mg^{2+} by atomic absorption spectrophotometry; Al^{3+} by titration. P and K: Mehlich 1.

To establish soil hydraulic parameters, the water retention curve was determined for each sample collected after winter, at tensions of 1, 6, 10, 33, 100, 500, 1000 and 1500 kPa. The Van Genuchten (1980) equation (equation 1) was fitted to the data.

$$\Theta\,(h) = \Theta r + \frac{(\Theta s - \Theta r)}{[1+(\alpha h)^n]^m} \quad (1)$$

Where: θ is the soil moisture (m^3 m^{-3}); θs total porosity (m^3 m^{-3}); θr residual moisture (m^3 m^{-3}); h the tension (kPa); and *α*, *n* and *m* are the fitting parameters.

Soil moisture was determined as follows: throughout the soybean and maize cycle, disturbed samples were collected from the layers 0.0-0.10, 0.10-0.20 and 0.20-0.30 m, at one point per plot, and then the gravimetric moisture was determined. Finally, volumetric moisture was computed as the product of gravimetric moisture by soil bulk density. During the maize and soybean cycle, soil moisture was quantified on 28 to 30 dates, evenly distributed throughout the crop cycle.

Based on the soil moisture and hydraulic parameters for each layer and management condition, the variation in soil water tension over time was evaluated and related to the critical values (h1, h2, h3 and h4) for plants, according to the model established by Feddes *et al*. (1978). In this model, the real transpiration rate(S) is a function of soil water tension (h), namely S(h) = *w*(h) x Sp, where Sp is the potential transpiration (in mm day^{-1}, for example), and *w* a parameter of potential transpiration reduction, where $0 \leq w \leq 1$. *w* is maximum (1) at tensions between h2 and h3 and minimum (0) at tensions lower than h1 and higher than h4. In addition, the value of *w* was assumed to change linearly between h1 and h2 and between h3 and h4. Therefore, the soil moisture corresponding to tensions between h2 and h3 represented the most favorable conditions for plant water uptake. For h1, h3 and h4, we used values of 1.5, 50, and 800 kPa, respectively, as is normally assumed for crops like maize in the vegetative stage in models such as Hydrus-1D (ŠIMŮNEK *et al.,* 2018). For h2, the tension corresponding to moisture with aeration porosity of 0.1 m^3 m^{-3} was used. In the 0.0-0.10 m layer, h2 was 48.8, 5.4 and 25.5 kPa for the treatments

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grazing, grazing + chiseling, and no grazing, respectively. In the 0.10-0.20 m layer, h2 was 48.8 kPa, and 25.5 kPa in the 0.20-0.30 m layer.

Soybean and maize root distribution were assessed during flowering. Initially, trenches (0.6 m wide and 0.5 m deep) were opened (TAVARES FILHO *et al.,* 1999) parallel to the plant rows in each plot. Subsequently, the roots were exposed for photographs and qualitative analysis of spatial distribution. The yields were evaluated at physiological maturation of the crops: for soybean and maize, respectively, all plants were removed from an area of 2.7 and 4.5 m², at one point per plot. The grain weight of both crops was determined and adjusted to 13 % moisture.

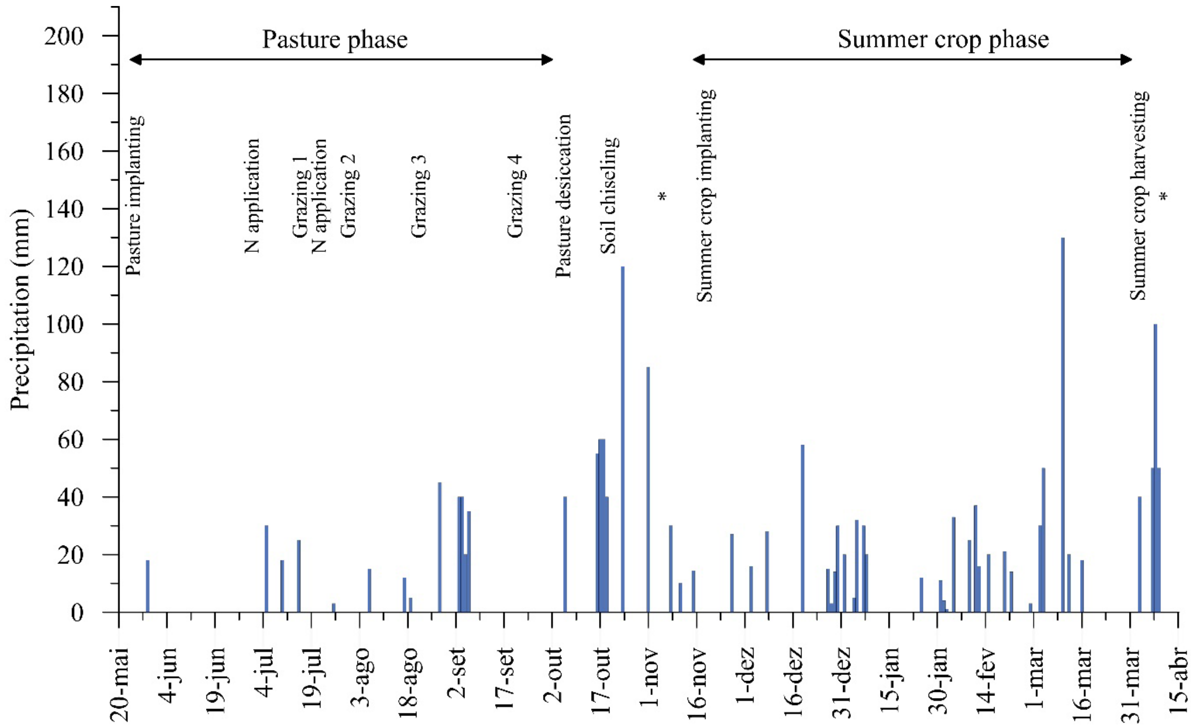

Figure 1. Rainfall distribution during the experimental period (second study year, 2016/2017) and dates of the main soil management and sampling operations. *Collection of undisturbed soil samples.

Statistical analysis

For each soil layer and evaluation period, the effect of treatments was analyzed by analysis of variance ($p < 0.05$) followed by comparison of means by the Tukey test ($p < 0.05$) for the soil physical properties (bulk density, macroporosity and microporosity) on the one hand and soybean and maize yield on the other. The residuals of the models were normal, independent and variance was homogeneous. To fit the water retention curves for each layer and treatment, the objective function was the minimization of the residual sum of squares between the observed and fitted values.

Results and Discussion

The soil physical properties evaluated prior to the experiment indicated pre-compaction in the 0.10-0.20 m layer, probably due to the sequence of

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no-tillage cultivation in the area. For example, in the 0-0.10, 0.10-0.20 and 0.20-0.30 m layers, soil bulk density was 1.31, 1.41 and 1.30 Mg m^{-3}, the macroporosity was 0.10, 0.08 and 0.10 m^3 m^{-3}, and the microporosity of 0.43, 0.42 and 0.44 m^3 m^{-3}, respectively, at the beginning of the experiment. Macroporosity of less than 0.10 m^3 m^{-3} and bulk density above 1.4 Mg m^{-3} (considering soil texture) - as seen in the 0.10-0.20 m layer - are warnings of critical conditions for an adequate functioning of soil and plants (REICHERT *et al.,* 2007).

The soil moisture preceding each grazing (0.0-0.10 m layer) was lower than the plasticity limit in all grazing cycles, which indicates favorable moisture conditions for grazing to minimize the impact of soil trampling (Table 2). For example, gravimetric moisture varied from 0.17 to 0.29 g g^{-1} between grazings, while the soil plasticity limit was 0.33 g g^{-1}. Moisture did not vary between the treatments grazing and grazing+chiseling. On the other hand, defoliation severity in the grazing treatment was high, especially in the first cycle (66 – 74 %) (Table 2). Dry biomass on the soil prior to grazing ranged from 0.8 to 4.5 Mg ha^{-1} (Table 2). Post-grazing biomass, on the other hand, ranged from 0.2 to 3.2 Mg ha^{-1}. In general, pre- and post-grazing biomass increased and defoliation severity decreased from the first to the last grazing cycle (Table 2). The final winter residue after the grazing and grazing+chiseling treatments was only 2.4 Mg ha^{-1} (Table 2), i.e., 68 % lower than in the control area (7.4 Mg ha^{-1}). It is worth mentioning that the amount of post-grazing residue was below the minimum amount (3 - 5.8 Mg ha^{-1}) that has to be contributed in the pasture phase to ensure the maintenance of environmental services and soil carbon stocks in integrated crop-livestock systems in Southern Brazil (ASSMAN *et al.,* 2013).

Cumulative precipitation during the summer crop cycle was 983 mm, and around 32 % was accumulated in the first 60 days of the crop cycle (Fig. 1). In view of the average rainfall patterns of the study region, this accumulation was considered high. Additionally, rainfall was relatively well distributed (Fig. 1). For example, the mean period between two days with rainfall was 4.03 days (± 2.93) (Fig. 1). Consequently, soil moisture remained high throughout most of the crop cycle in the 0.10-0.20 and 20-0.30 m layers. Moreover, the potential transpiration reduction factor increased from layer 0.0-0.10 to 0.20-0.30 m, indicating increasing water availability with increasing soil depth.

Trampling by dairy cows increased soil bulk density and decreased soil macroporosity (0.0-0.05 m) (Fig. 2). This result in annual pastures was to be expected, particularly at high grazing intensity (AMBUS *et al.,* 2018; BONETTI *et al.,* 2019; KOPPE *et al.,* 2021). However, the level at which trampling altered the soil physical properties, e.g., bulk density and porosity, in this study, appears to be greater than under continuous grazing systems in southern Brazil for the same soil type (AMBUS *et al.,* 2018; BONETTI *et al.,* 2019). Furthermore, soil density in the grazed area exceeded the critical value of 1.4 Mg ha^{-1} (REICHERT *et al.,* 2007) (Fig. 2). On the other hand, trampling did not disrupt the natural ability of the soil to return to its initial state during the summer crop cycle (Fig. 2), corroborating other studies (AMBUS *et al.,* 2018; BONETTI *et al.,* 2019; GREENWOOD and MCKENZIE, 2001; KOPPE *et al.,* 2021). Possibly, prior to grazing, soil moisture was not favorable for a more critical compaction due to trampling (Table

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2). It is however important to mention that soil tillage in the plant row seems to have played a role in improving physical properties (differences in bulk density and macroporosity within and between plant rows shown in Fig. 2).

Animal trampling increased soil moisture (reduced water tension) throughout the soybean and maize cycles (Fig. 3), which indicated (i) an increased frequency of plant restrictions due to oxygen limitation, but (ii) reduced water restrictions. Conversely, animal trampling caused no negative impact on the potential transpiration reduction factor (Fig. 3). Although macroporosity was reduced by trampling (Fig. 2), soil moisture was rarely high enough to limit soil aeration. For example, although rainfall was frequent and the soil was periodically saturated or nearly saturated, the rapid drainage of the surface layer and evaporation contributed to quickly restore adequate moisture levels for air availability after rains. In addition, the attenuation of water restriction due to the increase in soil moisture caused by trampling compensated for the lower air availability (Fig. 3).

Table 2. Soil moisture in the 0.0-0.10 m layer before each grazing cycle, aboveground biomass before and after grazing and defoliation severity after each grazing cycle.

Block	Date	Grazing cycle	Antecedent soil moisture (g g^{-1})			Pre-grazing biomass (Mg DM ha^{-1})		Post-grazing biomass (Mg DM ha^{-1})		Defoliation severity (%)	
			G	G+C	PL	G	G+C	G	G+C	G	G+C
1	19/07/2016	1	0.25	0.28	0.33	0.9	0.8	0.2	0.2	74	73
2	21/07/2016	1	0.24	0.26	0.33	0.9	0.9	0.3	0.3	72	72
3	23/07/2016	1	0.25	0.24	0.33	0.9	1.0	0.3	0.3	66	70
4	26/07/2016	1	0.23	0.22	0.33	1.2	1.2	0.4	0.4	66	68
1	03/08/2016	2	0.21	0.22	0.33	0.8	0.6	0.3	0.3	64	55
2	08/08/2016	2	0.23	0.23	0.33	1.2	1.4	0.7	0.6	45	60
3	10/08/2016	2	0.22	0.22	0.33	1.4	1.1	0.8	0.6	41	47
4	15/08/2016	2	0.20	0.21	0.33	2.0	2.3	1.1	1.2	43	49
1	25/08/2016	3	0.20	0.21	0.33	1.5	1.3	0.9	0.8	42	34
2	29/08/2016	3	0.29	0.29	0.33	1.5	1.3	0.8	0.8	47	43
3	06/09/2016	3	0.28	0.29	0.33	2.1	1.6	1.2	0.9	42	43
4	08/09/2016	3	0.27	0.27	0.33	2.8	2.7	1.7	1.8	38	32
1	24/09/2016	4	0.20	0.20	0.33	3.8	2.9	2.5	1.9	34	32
2	26/09/2016	4	0.20	0.20	0.33	2.9	2.9	2.3	2.0	23	31
3	28/09/2016	4	0.18	0.20	0.33	3.3	3.6	2.0	2.2	38	38
4	30/09/2016	4	0.20	0.17	0.33	4.2	4.5	3.1	3.2	24	29
Average	-	-	0.23	0.23	-	2.0	1.9	1.2	1.1	48	49
No Grazing	-	-	-	-	-	-	-	7.4 (± 0.7)*	-	-	-

*Biomass assessed in the control area in the flowering period and averaged across the four blocks. G: grazing; G+C: grazing and chiseling. PL: plasticity limit. DM: Dry matter.

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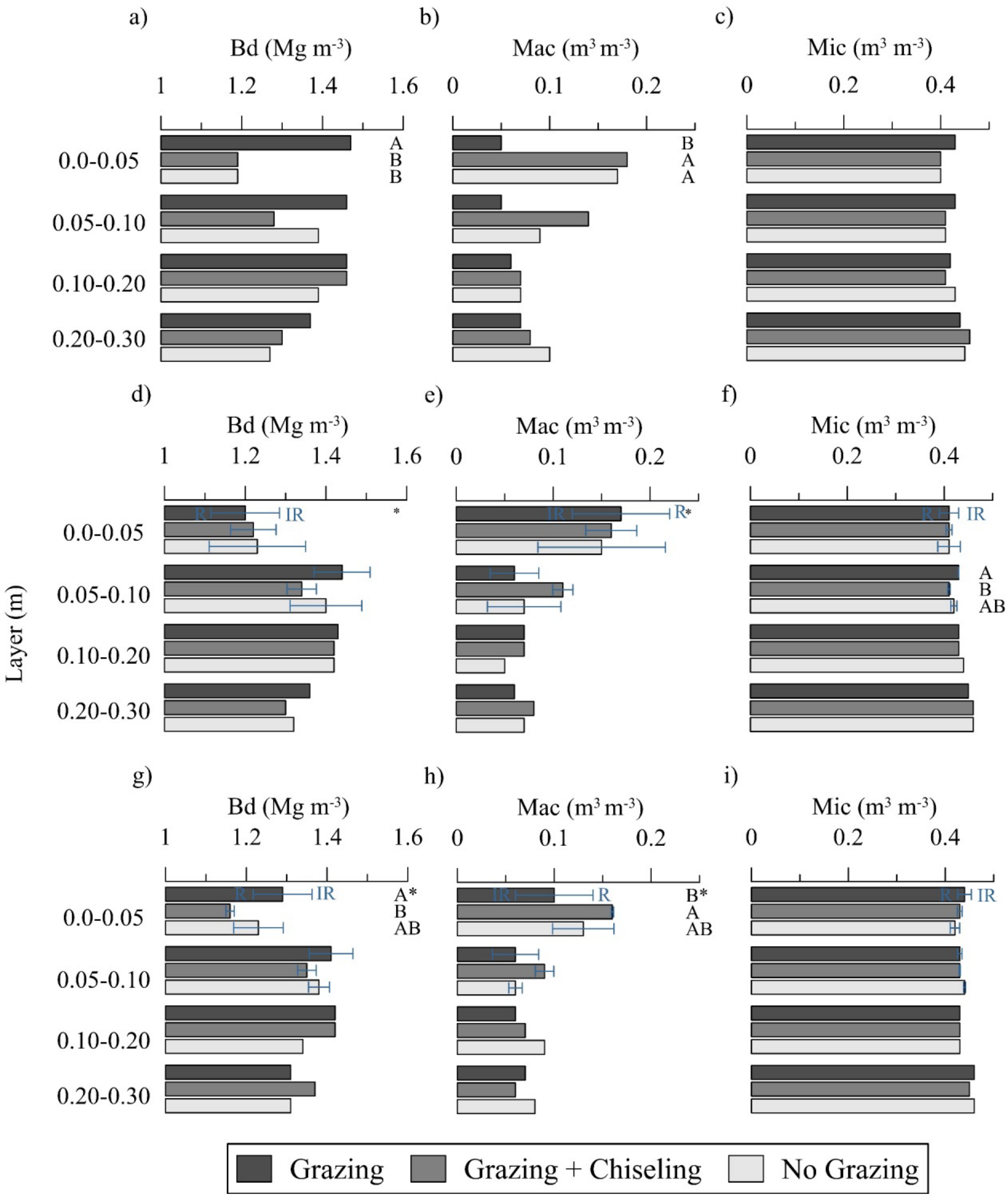

Figure 2. Soil bulk density (Bd), macroporosity (Mac) and microporosity (Mic) in periods after winter (a, b, c) and after soybean (d, e, f) and maize (g, h, i), under different management conditions in an integrated dairy crop-livestock system. Means followed by different letters for each layer and period and evaluation differed by the Tukey test ($p < 0.05$). R: plant row; IR: in-between plant rows. The error bar, when present, demonstrates the significant variation between R and IR. An asterisk indicates a difference compared to the post-winter period by the Tukey test ($p < 0.05$). Grazing - dairy cattle grazing in winter; Grazing + Chiseling - dairy cattle grazing in winter followed by soil chiseling; No Grazing - no dairy cattle grazing in winter.

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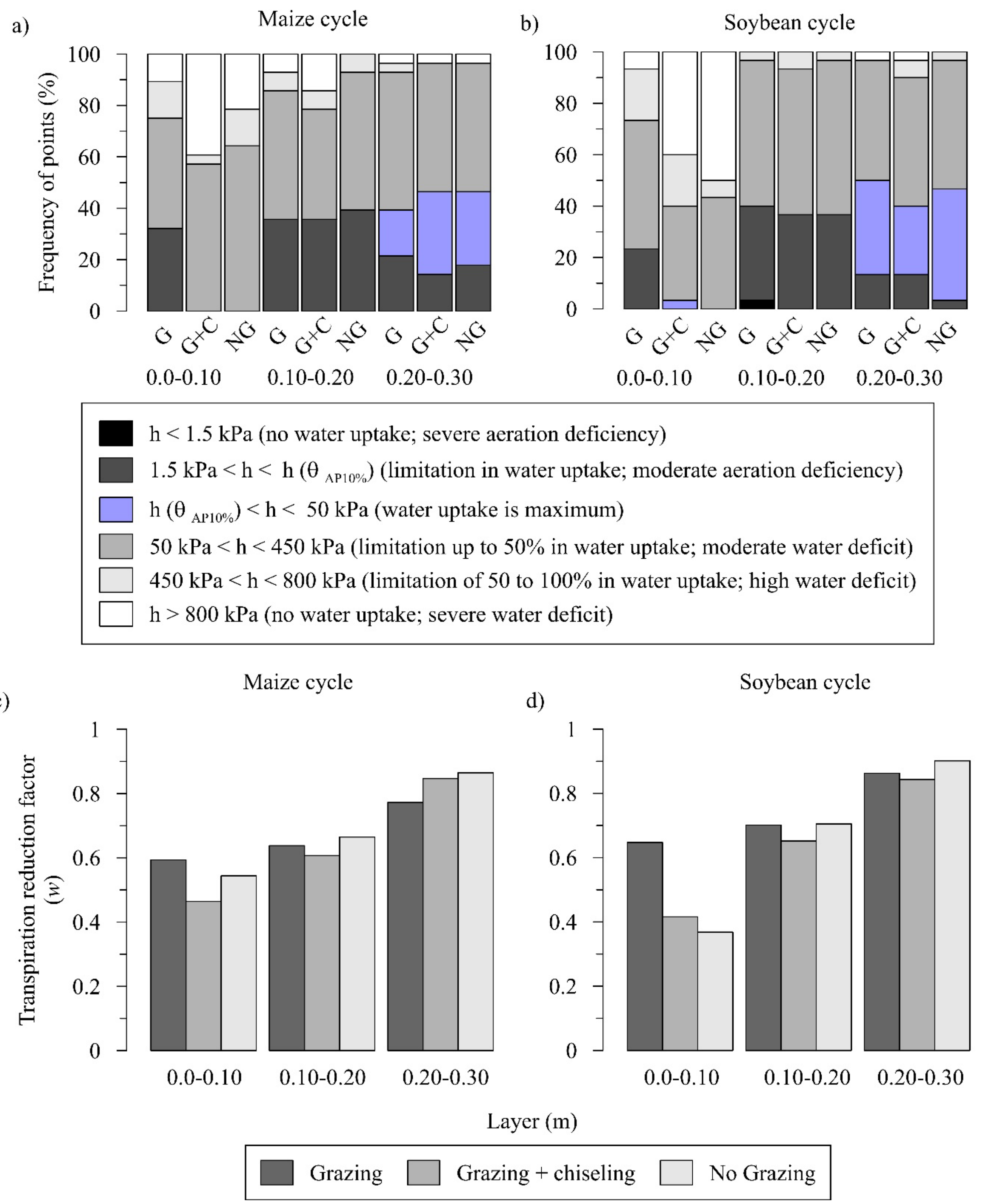

Figure 3. Frequency of time points during the maize (a) and soybean (b) cycle at which soil water tension (h) remained in different ranges of water availability, according to the model proposed by Feddes *et al*. (1978); and mean potential transpiration reduction factor (w) for maize (c) and soybean (d), where transpiration is maximum when $w = 1$. $\theta_{AP10\%}$ is the volumetric moisture for an aeration porosity of 10 %. Grazing (G) - dairy cattle grazing in winter; Grazing + Chiseling (G+C) - dairy cattle grazing in winter followed by soil chiseling; No Grazing (NG) - no dairy cattle grazing in winter.

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Soil chiseling reduced soil bulk density and increased soil macroporosity (Fig. 2), but reduced soil moisture and did not improve the balance between air and water availability (Fig. 3), which corroborates other authors (KUNZ *et al.,* 2013; MORAES *et al*., 2020; VIZIOLI *et al.,* 2019). According to Kunz *et al*. (2013), this operation can even reduce maize yield in an integrated crop-livestock system in years with below-average cumulative rainfall. Furthermore, chiseling coincided with the time of year with the highest cumulative rainfall (Fig. 1). Consequently, water erosion can be intensified by soil movement and greater exposure to raindrop impact (DEUSCHLE *et al.,* 2019). On the other hand, Secco *et al*. (2009) observed an increase in maize yield after chiseling of a severely compacted area under no tillage. The reason is that soil compaction caused by machines critically alters more factors directly related to plants than compaction caused by animal trampling. According to these authors, soybean was less susceptible to the effects of soil compaction than maize, which was not observed in this study.

The plants developed well and explored the soil profile down to a depth of approximately 0.5 m (data not shown). This demonstrates that animal trampling and the pre-compacted layer in 0.10-0.20 m did not affect the water access by the plants. Consequently, as management interfered only slightly with the potential transpiration reduction factor (Fig. 3), yields were not altered by the treatments. The mean soybean and maize yields were 3.8 and 10.1 Mg ha^{-1}, respectively, which is relatively high for the study region.

It was concluded that in years with abundant water, grazing by dairy cows in integrated crop-livestock systems in southern Brazil compacts the soil surface, whereas the yields of the subsequent crops (soybean or maize) are not affected. Secondly, soil chiseling after grazing can loosen the soil surface but cannot improve soil physical processes related to plant growth and development.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical Statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content, and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

According to ethical guidelines, there was no animal handling in the experimentation of this article. Therefore, there is no need for ethical approval for animal experimentation according to Brazilian standards.

The authors assume full responsibility for the originality of the article and may incur on them, any charges arising from claims, by third parties, in relation to the authorship of the article.

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References

ALLEN, V. G. *et al.* An international terminology for grazing lands and grazing animals. **Grass and Forage Science**, v. 66, n. 1, p. 2–28, 2011. https://doi.org/10.1111/j.1365-2494.2010.00780.x.

AMBUS, J. V. *et al.* Changes in composition and functional soil properties in long-term no-till integrated crop-livestock system. **Geoderma**, v. 330, p. 232–243, 2018. https://doi.org/10.1016/j.geoderma.2018.06.005.

ANGHINONI, I.; CARVALHO, P. C. D. F.; COSTA, S. E. V. G. De A. Abordagem sistêmica do solo em sistemas integrados de produção agrícola e pecuária no subtrópico brasileiro. *In*: ARAÚJO, A. P.; AVELAR, J. R. B. (Org.). Tópicos em Ciência do Solo. 8. ed. Viçosa: Sociedade Brasileira de Ciência do Solo, 2013. v. 8, p. 325–380.

ASSMANN, J. M. *et al.* Soil carbon and nitrogen stocks and fractions in a long-term integrated crop–livestock system under no-tillage in southern Brazil. **Agriculture, Ecosystems and Environment**, v. 190, p. 52–59, 2013. http://dx.doi.org/10.1016/j.agee.2013.12.003.

BELL, L. W. *et al.* Impacts of soil damage by grazing livestock on crop productivity. **Soil and Tillage Research**, v. 113, n. 1, p. 19–29, 2011. https://doi.org/10.1016/j.still.2011.02.003.

BONETTI, J. A. *et al.* Impact of a long-term crop-livestock system on the physical and hydraulic properties of an Oxisol. **Soil and Tillage Research**, v. 186, p. 280–291, 2019. https://doi.org/10.1016/j.still.2018.11.003.

CARVALHO, P. C. De F. *et al.* Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. **Nutrient Cycling in Agroecosystems**, p. 259–273, 2010. https://doi.org/10.1007/s10705-010-9360-x.

CARVALHO, P. C. F. *et al.* Animal production and soil characteristics from integrated crop-livestock systems: toward sustainable intensification. **Journal of Animal Science**, v. 96, p. 3513–3525, 2018. https://doi.org/10.1093/jas/sky085.

CECAGNO, D. *et al.* Least limiting water range and soybean yield in a long-term, no-till, integrated crop-livestock system under different grazing intensities. **Soil and Tillage Research**, v. 156, p. 54–62, 2016. https://doi.org/10.1016/j.still.2015.10.005.

CQFS. **Manual de calagem e adubação para os estados do Rio Grande do Sul e de Santa Catarina**. Comissão de Química e Fertilidade do Solo - RS/SC, 2016. Available from: https://www.sbcs-nrs.org.br/docs/Manual_de_Calagem_e_Adubacao_para_os_Estados_do_RS_e_de_SC-2016.pdf. Accessed: Feb. 10, 2023.

DEUSCHLE, D. *et al*. Erosion and hydrological response in no-tillage subjected to crop rotation intensification in southern Brazil. **Geoderma**, v. 340, p. 157–163, 2019. https://doi.org/10.1016/j.geoderma.2019.01.010.

DREWRY, J. J. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: A review. **Agriculture, Ecosystems and Environment**, v. 114, n. 2–4, p. 159–169, 2006. https://doi.org/10.1016/j.agee.2005.11.028.

DREWRY, J. J; CAMERON, K. C.; BUCHAN, G. D. Pasture yield and soil physical property responses to soil compaction from treading and grazing - A review. **Australian Journal of Soil Research**, v. 46, n. 3, p. 237–256, 2008. https://doi.org/10.1071/SR07125.

DREWRY, J. J; PATON, R. J. Effects of cattle treading and natural amelioration on soil physical properties and pasture under dairy farming in Southland, New Zealand. **New Zealand Journal of Agricultural Research**, v. 43, n. 3, p. 377–386, 2000. https://doi.org/10.1080/00288233.2000.9513438.

DREWRY, J. J; PATON, R. J; MONAGHAN, R. M. Soil compaction and recovery cycle on a Southland dairy farm: Implications for soil monitoring. **Australian Journal of Soil Research**, v. 42, n. 7, p. 851–856, 2004. https://doi.org/10.1071/SR03169.

EMBRAPA. **Manual de métodos de análise de solo**. 3. ed. Rio de Janeiro: Centro Nacional de Pesquisa de Solos, Embrapa, 2017. Available from: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1085209/manual-de-metodos-de-analise-de-solo. Accessed: Feb. 5, 2023.

EMBRAPA. **Sistema Brasileiro de Classificação de Solos**. 5. ed. Brasília: 2018. Available from: https://www.embrapa.br/solos/sibcs. Accessed: Feb. 5, 2023.

FEDDES, R. A.; KOWALIK, P. L.; ZARADNY, H. Simulation of field water use and crop yield. **Centre for Agricultural Publishing and Documentation, Wageningen**. 1978. Available from: https://lib.ugent.be/catalog/rug01:000032129. Accessed: Feb. 5, 2023.

FAO. An international consultation on integrated crop-livestock systems for development - The Way Forward for Sustainable Production. **Integrated Crop Managment**, v. 13, p. 79, 2010. Available from: https://www.fao.org/3/i2160e/i2160e.pdf. Accessed: Feb. 10, 2023.

GREENWOOD, K. L.; MCKENZIE, B. M. Grazing effects on soil physical properties and the consequences for pastures: a review. **Australian**

Received on 25 May 2023. Accepted on 15 March. 2024.

Journal of Experimental Agriculture, v. 41, p. 1231–1250, 2001. https://doi.org/10.1071/EA00102.

GUBIANI, P. I. *et al*. Transpiration reduction factor and soybean yield in low land soil with ridge and chiseling. **Revista Brasileira de Ciencia do Solo**, v. 42, p. 1–14, 2018. https://doi.org/10.1590/18069657rbcs20170282.

HOULBROOKE, D. J. *et al*. Grazing strategies to protect soil physical properties and maximise pasture yield on a Southland dairy farm. **New Zealand Journal of Agricultural Research**, v. 52, p. 323–336, 2009. https://doi.org/10.1080/00288230909510517.

KAISER, D. R. *et al*. Soil physical capacity and intensity properties for achieving sustainable agriculture in the subtropics and tropics: a review. *In*: KRÜMMELBEIN, J.; HORN, R.; PAGLIAI, M. (Org.). **Advances in Geoecology: Soil Degradation**, p. 282–339, 2013.

KOPPE, E. *et al*. Physical recovery of an oxisol subjected to four intensities of dairy cattle grazing. **Soil and Tillage Research**, v. 206, p. 104813, 2021. https://doi.org/10.1016/j.still.2020.104813.

KUNZ, M. *et al*. Compactação do solo na integração soja-pecuária de leite em Latossolo argiloso com semeadura direta e escarificação. **Revista Brasileira de Ciencia do Solo**, v. 37, p. 1699–1708, 2013. https://doi.org/10.1590/S0100-06832013000600026.

LEÃO, T. P. *et al*. Intervalo hídrico ótimo na avaliação de sistemas de pastejo contínuo e rotacionado. **Revista Brasileira de Ciencia do Solo**, v. 28, p. 415–422, 2004. https://doi.org/10.1590/s0100-06832004000300002.

LEMAIRE, G. *et al*. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. **Agriculture, Ecosystems and Environment**, v. 190, p. 4–8, 2014. https://doi.org/10.1016/j.agee.2013.08.009.

MORAES, A. *et al*. Integrated crop-livestock systems in the Brazilian subtropics. **European Journal of Agronomy**, v. 57, p. 4–9, 2014. https://doi.org/10.1016/j.eja.2013.10.004.

MORAES, M. T. De *et al*. Soil compaction impacts soybean root growth in an Oxisol from subtropical Brazil. **Soil and Tillage Research**, v. 200, n. March, p. 104611, 2020. https://doi.org/10.1016/j.still.2020.104611.

REICHERT, J. M.; SUZUKI, L. E. A. S.; REINERT, D. J. Compactação do solo em sistemas agropecuários e florestais: identificação, efeitos, limites críticos e mitigação. *In*: CERETTA, C. A.; SILVA, L. S.; REICHERT, J. M. (Org.). **Tópicos em Ciência do Solo**. 4. ed. Viçosa: Sociedade Brasileira de Ciência do Solo, p. 49–134, 2007.

SECCO, D. *et al*. Atributos físicos e rendimento de grãos de trigo, soja e milho em dois Latossolos compactados e escarificados. **Ciencia Rural**, v. 39, p. 58–64, 2009. https://doi.org/10.1590/S0103-84782009000100010.

ISSN: 0104-9070 ISSN ONLINE: 2595-7686.
Received on 25 May 2023. Accepted on 15 March. 2024.

ŠIMŮNEK, J. *et al*. **The HYDRUS-1D Software Package for Simulating the Movement of Water, Heat, and Multiple Solutes in Variably Saturated Media, Version 4.17, HYDRUS Software Series 3**. Department of Environmental Sciences, University of California Riverside. 2018.

SOIL SURVEY STAFF. Keys to soil taxonomy – Soil Survey Staff, twelfth edition. US Departament of Agriculture, Washington D.C 2014. Available from: https://nrcspad.sc.egov.usda.gov/DistributionCenter/product.aspx?ProductID=1059. Accessed: Feb. 10, 2023.

TAVARES FILHO, J. *et al*. Método do Perfil Cultural para avaliação do estado físico de solos em condições tropicais. **Revista Brasileira de Ciência do Solo**, v. 23, p. 393–399, 1999. https://doi.org/10.1590/s0100-06831999000200022.

TRACY, B. F.; ZHANG, Y. Soil Compaction, corn yield Response, and soil nutrient pool dynamics within an integrated crop-livestock system in illinois. **Crop Science**, v. 48, p. 1211–1218, 2008. https://doi.org/10.2135/cropsci2007.07.0390.

VAN GENUCHTEN, M. T. A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. **Soil Sci. Soc. Am. J.**, v. 8, p. 892–898, 1980. Available from: https://acsess.onlinelibrary.wiley.com/doi/abs/10.2136/sssaj1980.03615995004400050002x. Accessed: Feb. 10, 2023.

VIZIOLI, B.; CAVALIERI-POLIZELI, K. M. V.; BARTH, G. Silage yield , organic carbon content and physical attributes of a chiseled Ferralsol under an integrated crop-livestock system. **Revista Brasileira de Ciências Agrárias**, v.14, n.3, p. 1–9, 2019. https://doi.org/10.5039/agraria.v14i3a6710

ISSN: 0104-9070 ISSN ONLINE: 2595-7686.
Received on 25 May 2023. Accepted on 15 March. 2024.