Dairy cattle grazing compacts soil surface without reducing subsequent crop yield

Lucas Raimundo Rauber1*, Douglas Rodrigo Kaiser2, Renan Costa Beber Vieira2, Micael Stolben Mallman1, Dalvan José Reinert1

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 manejo 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 e escarificação do solo em inverno; 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.


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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...
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 m² per plot was removed from the soil and oven-dried at 60 °C 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-
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.

<table>
<thead>
<tr>
<th>Layer (m)</th>
<th>Clay</th>
<th>Loam</th>
<th>Sand</th>
<th>OM (%)</th>
<th>pH water</th>
<th>Ca(^{2+})</th>
<th>Mg(^{2+})</th>
<th>Al(^{3+})</th>
<th>P (mg dm(^{-3}))</th>
<th>K(^{+}) (mg dm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.10</td>
<td>590</td>
<td>300</td>
<td>110</td>
<td>3</td>
<td>5</td>
<td>6.5</td>
<td>2.9</td>
<td>0.4</td>
<td>28.2</td>
<td>216</td>
</tr>
<tr>
<td>0.10-0.20</td>
<td>630</td>
<td>290</td>
<td>80</td>
<td>2.3</td>
<td>5.7</td>
<td>7.4</td>
<td>2.9</td>
<td>0</td>
<td>10</td>
<td>120</td>
</tr>
</tbody>
</table>

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.

\[ \theta (h) = \theta_r + \frac{(\theta_s - \theta_r)}{[1 + (\alpha h)^n]^m} \]

(1)

Where: \( \theta \) is the soil moisture (m\(^3\) m\(^{-3}\)); \( \theta_s \) total porosity (m\(^3\) m\(^{-3}\)); \( \theta_r \) residual moisture (m\(^3\) m\(^{-3}\)); \( h \) the tension (kPa); and \( a, n \) 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 (\( h_1, h_2, h_3 \) and \( h_4 \)) 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 \( S(h) = w(h) \times S_p \), where \( S_p \) 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 \( h_2 \) and \( h_3 \) and minimum (0) at tensions lower than \( h_1 \) and higher than \( h_4 \). In addition, the value of \( w \) was assumed to change linearly between \( h_1 \) and \( h_2 \) and between \( h_3 \) and \( h_4 \). Therefore, the soil moisture corresponding to tensions between \( h_2 \) and \( h_3 \) represented the most favorable conditions for plant water uptake. For \( h_1, h_3 \) and \( h_4 \), 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 \( h_2 \), 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, \( h_2 \) was 48.8, 5.4 and 25.5 kPa for the treatments.
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
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
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.

<table>
<thead>
<tr>
<th>Block</th>
<th>Date</th>
<th>Grazing cycle</th>
<th>Antecedent soil moisture (g g⁻¹)</th>
<th>Pre-grazing biomass (Mg DM ha⁻¹)</th>
<th>Post-grazing biomass (Mg DM ha⁻¹)</th>
<th>Defoliation severity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>G</td>
<td>G+C</td>
<td>PL</td>
<td>G</td>
</tr>
<tr>
<td>1</td>
<td>19/07/2016</td>
<td>1</td>
<td>0.25</td>
<td>0.28</td>
<td>0.33</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>21/07/2016</td>
<td>1</td>
<td>0.24</td>
<td>0.26</td>
<td>0.33</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>23/07/2016</td>
<td>1</td>
<td>0.25</td>
<td>0.24</td>
<td>0.33</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>26/07/2016</td>
<td>1</td>
<td>0.23</td>
<td>0.22</td>
<td>0.33</td>
<td>1.2</td>
</tr>
<tr>
<td>1</td>
<td>03/08/2016</td>
<td>2</td>
<td>0.21</td>
<td>0.22</td>
<td>0.33</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>08/08/2016</td>
<td>2</td>
<td>0.23</td>
<td>0.23</td>
<td>0.33</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>10/08/2016</td>
<td>2</td>
<td>0.22</td>
<td>0.22</td>
<td>0.33</td>
<td>1.4</td>
</tr>
<tr>
<td>4</td>
<td>15/08/2016</td>
<td>2</td>
<td>0.20</td>
<td>0.21</td>
<td>0.33</td>
<td>2.0</td>
</tr>
<tr>
<td>1</td>
<td>25/08/2016</td>
<td>3</td>
<td>0.20</td>
<td>0.21</td>
<td>0.33</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>29/08/2016</td>
<td>3</td>
<td>0.29</td>
<td>0.29</td>
<td>0.33</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>06/09/2016</td>
<td>3</td>
<td>0.28</td>
<td>0.29</td>
<td>0.33</td>
<td>2.1</td>
</tr>
<tr>
<td>4</td>
<td>08/09/2016</td>
<td>3</td>
<td>0.27</td>
<td>0.27</td>
<td>0.33</td>
<td>2.8</td>
</tr>
<tr>
<td>1</td>
<td>24/09/2016</td>
<td>4</td>
<td>0.20</td>
<td>0.20</td>
<td>0.33</td>
<td>3.8</td>
</tr>
<tr>
<td>2</td>
<td>26/09/2016</td>
<td>4</td>
<td>0.20</td>
<td>0.20</td>
<td>0.33</td>
<td>2.9</td>
</tr>
<tr>
<td>3</td>
<td>28/09/2016</td>
<td>4</td>
<td>0.18</td>
<td>0.20</td>
<td>0.33</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>30/09/2016</td>
<td>4</td>
<td>0.20</td>
<td>0.17</td>
<td>0.33</td>
<td>4.2</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.23</td>
<td>-</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Grazing - No Grazing - G: grazing; G+C: grazing and chiseling. PL: plasticity limit. DM: Dry matter.*
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.
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.
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; VIZIOLO 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-compact 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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