



HAL
open science

The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil

Lucas Aquino Alves, Luiz Gustavo de Oliveira Denardin, Amanda Posselt Martins, Cimélio Bayer, Murilo G. Veloso, Carolina Bremm, Paulo César de Faccio Carvalho, Debora Rubin Machado, Tales Tiecher

► To cite this version:

Lucas Aquino Alves, Luiz Gustavo de Oliveira Denardin, Amanda Posselt Martins, Cimélio Bayer, Murilo G. Veloso, et al.. The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil. *Soil and Tillage Research*, 2020, 203, pp.104678. 10.1016/j.still.2020.104678 . hal-04260635

HAL Id: hal-04260635

<https://normandie-univ.hal.science/hal-04260635>

Submitted on 30 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Manuscript Details

Manuscript number	STILL_2019_1245_R2
Title	The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil
Article type	Research Paper

Abstract

Integrated crop-livestock systems (ICLS) conducted under no-tillage have been shown to favour accumulation of carbon (C) and nitrogen (N) in the soil, but this accumulation may depend on pasture management and crop rotation used, which will affect the amount and the quality of plant residues added to the soil. The objective of this study was to evaluate the impact of two stocking methods (continuous and rotational) and sheep grazing intensities (moderate and low) of winter pasture and the effect of summer crop rotation (soybean and/or maize) on crop yield and C and N stocks in an Acrisol after 14 years of experimentation. The evaluated ICLS was set up for grain yield in the summer crop phase and for sheep meat production in the winter pasture phase. Pasture dry mass production and soybean and corn yield were evaluated throughout the experimental period. After 14 years, soil was sampled at the 0-5, 5-10, 10-20 and 20-30 cm soil layers to evaluate the content and stock of soil C and N. Higher C and N content in soil superficial layers (0–5 and 5–10 cm) were observed under low grazing intensity in the winter and soybean monoculture in the summer. The C and N stocks in 0-30 cm soil layer ranged between 39 and 45 Mg C ha⁻¹ and 4 and 5 Mg N ha⁻¹, respectively. The C and N stocks in the soil were significantly related to the quantity of N present in the pasture and the summer crop residues. This is probably related to the higher efficiency of microbes in using crop residues, and posterior stabilization of microbial residues through organo-mineral association in the soil. The higher content and stocks of C and N associated with low intensity grazing favoured the higher maize yield (40%) compared to moderate grazing intensity in the 2015/2016 season. According to our results, the accumulation of C and N in the soil under the ICLS involving low grazing intensity in the winter and soybean monoculture in the summer was related to the N added/recycled by the soybean and by the hibernial pasture.

Keywords	Grazing intensities, Stocking methods, Soybean, Maize, Annual ryegrass
Taxonomy	Soil Organic C Storage, Soil Organic N Storage, Crop Yield
Manuscript category	Soil Management
Corresponding Author	Lucas Aquino Alves
Corresponding Author's Institution	Federal University of Rio Grande do Sul
Order of Authors	Lucas Aquino Alves, Luiz Gustavo Denardin, Amanda Martins, Cimelio Bayer, Murilo Veloso, Carolina Bremm, Paulo Cesar de Faccio Carvalho, Debora Rubin Machado, Tales Tiecher
Suggested reviewers	Frederico Costa Beber Vieira, Laurent CANER, Alan J. Franzluebbbers, sandeep kumar, EDUARDO MENDONÇA, Jeferson Dieckow, Gilles LEMAIRE

Submission Files Included in this PDF

File Name [File Type]

Cover_Letter_Carbon.docx [Cover Letter]

Letter_To_Reviewer_2.docx [Response to Reviewers]

Paper_Carbon_Revised_2.docx [Revised Manuscript with Changes Marked]

Highlights_Carbon_Revised.docx [Highlights]

Graphical_Abstract_Revised.docx [Graphical Abstract]

Paper_Carbon_Revised.docx [Manuscript File]

Figures_Carbon_Revised_2.pdf [Figure]

Tables_Carbon_Revised_2.docx [Table]

Declaration_of_Competing_Interests.docx [Conflict of Interest]

Supplementary_Material_Carbon.docx [e-Component]

Declaration_English_Revision.pdf [e-Component]

Animal_Use_Ethics_Committee.pdf [e-Component]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Research Data Related to this Submission

There are no linked research data sets for this submission. The following reason is given:
Data will be made available on request

Dear Editor,

The following manuscript "*The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil*" submitted for appreciation by **Soil & Tillage Research** is grounded in a long-term experiment (14-year) that evaluate the adoption of different crop-livestock systems involving the animal effect (sheep grazing) in winter pasture phase, with different stocking methods (continuous and rotational) and grazing intensities (moderate and low), and the cropping system in the summer with monoculture (soybean/soybean) or crop rotation (soybean/maize).

The treatments used for the present study, based on soybean and sheep-meat production, were chosen because it is a viable option for many South American small farmers. In this paper we presented a series of data of soybean and maize grain yield, and ryegrass dry matter production over the years, as well as content and stock of C and N for the 30 cm soil depth after 14 years of adoption of the experiment.

The main results indicated that low grazing intensity contribute to the increase of C stocks in the soil, favouring higher maize yield than moderate grazing intensity. In addition, greater stocks of C and N was observed under monoculture of soybean than crop rotation, due to the low yield and residue quality (high C/N ratio) of maize, which is deeply discussed in the paper.

Therefore, I believe that these data are relevant at a global level and allows the improvement of our knowledge regarding pasture management and crop rotation in integrated crop-livestock systems aiming obtain systems that favour great food production while increasing accumulation of C and N in soil.

I hereby inform that the manuscript was not published previously, and its submission was approved by all authors. If the article is accepted, it won't be published electronically in the same form, in English or in any other language, without the written consent of the copyright-holder.

Yours sincerely,

Porto Alegre, Brazil, 16th September 2019.

Lucas Aquino Alves (corresponding author)

PhD student in Soil Science

Universidade Federal do Rio Grande do Sul

7712 Bento Gonçalves Avenue, 91540-000, Porto Alegre, Rio Grande do Sul, Brazil

Phone: +55 (55) 9 9657 8147 | E-mail: lucasalves.la@hotmail.com

Dear Editor,

We are grateful for the editor's comments, which were of great importance to improve the final quality of the manuscript. All comments were carefully considered in the revision of the manuscript and highlighted in green. When not incorporated, our reasons for disagreeing were respectfully stated below.

Sincerely,
The Authors

Editor's question: How? What were the fields capacity and PWP limits? And please describe methodology, depth increments and number or replicates per plot.

Author response: The sentence was incorrect, so we changed it for the reader's better understanding (lines 177–181).

Editor's question: How much do these results depend on the time sampling during the season? Can the authors say something about temporal dynamics?

Author response: As our objective was not evaluate soil organic fractions, the stocks of soil organic carbon and total nitrogen have no (or small) variation in the short term (Cecagno et al., 2018; doi:10.5039/agraria.v13i3a5553) through the seasons. Also, we were attempted to sampling soil before sowing for annual crops, because the influence of root exudates or biomass mineralization from the previous crops is the lowest (Schieung et al., 2017; doi: 10.1016/S1002-0160(17)60326-6). We have included this information in Lines 197–200.

Also, our study brings the first evaluation regarding C and N evaluation after 14-y of experiment adoption. Thus, we could not infer about the temporal dynamic of stock of C and N.

Yours sincerely,

Porto Alegre, Brazil, March 04th 2020.

Lucas Aquino Alves (corresponding author)

PhD student in Soil Science

Universidade Federal do Rio Grande do Sul

7712 Bento Gonçalves Avenue, 91540-000, Porto Alegre, Rio Grande do Sul, Brazil

Phone: +55 (55) 9 9657 8147 | E-mail: lucasalves.la@hotmail.com

1 **The effect of crop rotation and sheep grazing management on plant**
2 **production and soil C and N stocks in a long-term integrated crop-**
3 **livestock system in Southern Brazil**

4
5 Lucas Aquino Alves^{a,*}, Luiz Gustavo de Oliveira Denardin^a, Amanda Posselt Martins^b,
6 Cimélio Bayer^b, Murilo Gomes Veloso^b Carolina Bremm^c, Paulo César de Faccio
7 Carvalho^c, Debora Rubin Machado^d, Tales Tiecher^{b,*}

8
9 ^a *Graduate Program in Soil Science, Interdisciplinary Research Group on Environmental*
10 *Biogeochemistry, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue 7712, 91540-000,*
11 *Porto Alegre, RS, Brazil*

12 ^b *Department of Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue 7712,*
13 *91540-000, Porto Alegre, RS, Brazil*

14 ^c *Animal Science Research Program, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue*
15 *7712, 91540-000, Porto Alegre, RS, Brazil*

16 ^d *Graduate Program in Animal Science, Grazing Ecology Research Group, Federal University of Rio*
17 *Grande do Sul, Bento Gonçalves Avenue 7712, 91540-000, Porto Alegre, RS, Brazil*

18
19 * Corresponding author

20 E-mail address: lucas.aquino@ufrgs.br (L. A. Alves)

21 E-mail address: tales.tiecher@ufrgs.br (T. Tiecher)

22 **The effect of crop rotation and sheep grazing management on plant**
23 **production and soil C and N stocks in a long-term integrated crop-**
24 **livestock system in Southern Brazil**

25
26 **Abstract**

27 Integrated crop-livestock systems (ICLS) conducted under **no-till** have been shown to
28 favour the accumulation of carbon (C) and nitrogen (N) in soil. In **those** systems, however,
29 C and N accumulation in soil might depend on pasture management and the type of crop
30 rotation used. The objective of this study was to evaluate the impact of two stocking
31 methods (continuous and rotational) and two sheep grazing intensities (moderate and low)
32 on winter pasture and the effect of summer crop rotation (soybean **and** maize) on crop
33 yield and C and N stocks in an Acrisol after 14-yr under experimental conditions. The
34 evaluated ICLS was set up for grain yield in the summer crop phase and for sheep meat
35 production in the winter pasture phase. Pasture production, soybean and corn yield were
36 evaluated throughout the experimental period. After 14-yr, the soil was sampled at the 0–
37 5, 5–10, 10–20 and 20–30 cm layers to evaluate the content and stock of C and N. Higher
38 C and N contents in soil **surface** layers (0–5 and 5–10 cm) were observed under low
39 grazing intensity in winter and soybean monoculture in summer. The C and N stocks in
40 0-30 cm soil layer ranged between 39 and 45 Mg C ha⁻¹ and 4 and 5 Mg N ha⁻¹,
41 respectively. C and N stocks in the soil were significantly related to N added through the
42 residues of pasture and summer crop. This positive relationship is possibly explained by
43 the higher efficiency of microbes in using crop residues enriched in N with posterior
44 stabilization of microbial residues through organo-mineral association in the soil. The
45 higher content and stocks of C and N associated with low intensity grazing favoured a
46 higher maize yield (40%) compared to moderate grazing intensity in the 2015/2016
47 season. According to our results, the accumulation of C and N in the soil under ICLS
48 involving low grazing intensity in the winter and soybean monoculture in the summer
49 was related to the N added/recycled by the soybean and by the hibernal pasture.

50
51 **Keywords:** Grazing intensities, Stocking methods, Soybean, Maize, Annual ryegrass.

52 1. Introduction

53 Soil organic matter (SOM) influences the chemical, physical and biological
54 conditions in the soil as well as **determines** its productive capacity (Ghosh et al., 2010;
55 Lal, 2004). The SOM content is affected by soil management, and crop systems with high
56 input of plant residues **such as no-tillage** have been shown as strategies to favour SOM
57 accumulation (Bayer et al., 2006; Veloso et al., 2018). In addition to quantity, the residues
58 with better quality (**higher** N content) may result in a greater efficiency of substrate use
59 by the microbiota and **contribute** to accumulation of C and N in the soil (Cotrufo et al.,
60 2013; 2015).

61 Integrated crop-livestock systems (ICLS) are defined as systems in which there is
62 temporary alternation or rotation of pastures and crops in the same area over time (Moraes
63 et al., 2014), contributing to the accumulation of C and N in the soil (Sá et al., 2017; Luz
64 et al., 2019). C and N accumulation **depends** on the stocking method, grazing intensity in
65 the pasture phase and on the choice of summer crops (Carvalho et al., 2010). Results have
66 highlighted the importance of the intensity and the method of animal grazing during
67 hibernal grazing **for** the accumulation of SOM, which is largely related to the impact of
68 grazing intensity on root system development (Reeder and Schuman, 2002). However,
69 lack of information **exists** regarding the impact of ICLS **in** different production
70 management systems on soil C and N stocks in subtropical environments.

71 Among the commercial crops utilized during summer in the subtropics, soybean
72 stands out for its large cultivated area, currently estimated at 35.8 million hectares in
73 Brazil, of which 11.9 million are cultivated in three southern states (Paraná, Santa
74 Catarina and Rio Grande do Sul) (CONAB, 2019). The soybean residue has low C/N
75 ratio, that in turn, may increase **the** N availability due to **low** soil immobilization by
76 microorganisms and, therefore, favour the development of pasture after soybeans

77 (Campos, 2015). On the other hand, the insertion of maize into crop rotation with
78 soybeans propitiate a greater quantity of plant residues, **however** with a **low** quality
79 **because of a high** C/N ratio compared to soybeans alone (Chen et al., 2018). In subtropical
80 Brazil, maize cultivation is less attractive for local farmers due to the frequent occurrence
81 of water deficits that **strongly** impact maize yield, due to its higher sensitivity to water
82 deficit mainly at the flowering stage compared to soybeans (Steduto et al., 2012).

83 Thus, there is a need for results that could guide the impact of the stocking method,
84 grazing intensity in the pasture phase and the crops adopted in the cropping phase on soil
85 C and N stocks and the **crop yields**. Therefore, this study aimed to evaluate the impact of
86 grazing (stocking method and grazing intensity) in hibernal pasture and cash crops
87 (monoculture of soybean, and crop rotation of soybean and maize) in the cropping phase
88 on soil C and N stocks, pasture production, soybean and maize yield in the Brazilian
89 subtropics. The study was conducted over 14-yr in an ICLS with grain and sheep-meat
90 production in an Acrisol in the Brazilian subtropics.

91

92 **2. Material and methods**

93 *2.1. Description of the experiment*

94 A long-term study was conducted using an ICLS implanted in 2003, in the
95 Experimental Agronomic Station of the Federal University of Rio Grande do Sul, in
96 Eldorado do Sul county, Rio Grande do Sul state, Brazil (latitude 30°05'S, longitude
97 51°39'O, altitude 46 m). The local climate is classified as subtropical humid (Cfa)
98 according to the Köppen classification (Kottek et al., 2006). The average annual rainfall
99 over the 14-yr experimental period ranged between 1200 and 2000 mm, with an average
100 annual temperature of 19 °C.

101 The soil was classified as a sandy clay loam Acrisol (FAO, 2006). At the
102 beginning of the experiment, the 0-10 cm soil layer presented organic C content of 17 g
103 kg⁻¹, pH-water (1:1 soil/water ratio) of 5.3; exchangeable aluminium (Al), calcium (Ca)
104 and magnesium (Mg) (KCl 1.0 mol L⁻¹) of 0.3, 2.2 and 1.2 cmol_c kg⁻¹, respectively;
105 available phosphorus (P) and potassium (K) (Mehlich 1) of 10 and 135 mg kg⁻¹,
106 respectively; base and Al saturation of 51% and 8%, respectively.

107 Prior to the experiment, the area was natural grassland of the Pampa Biome,
108 **overseed** with exotic species in the winter, such as ryegrass (*Lolium multiflorum*). The
109 area was desiccated with glyphosate herbicide and limestone was applied (1.0 Mg ha⁻¹)
110 to raise the soil pH (in water) in the 0-10 cm soil layer to 6.0.

111 At the beginning of the experimental period, the area was fertilized with 18 kg P
112 ha⁻¹ and 33 kg K ha⁻¹, which is the amount of fertilizer needed for an expected soybean
113 yield of 3.0 Mg ha⁻¹ (CFS-RS/SC, 1995, CQFS-RS/SC, 2004). Almost every year,
114 ryegrass was sown at a density of 32 kg ha⁻¹ in the autumn-winter period and fertilized
115 with nitrogen split in two applications, of 150 kg N ha⁻¹ as urea.

116 The experimental area of 4.5 ha was divided into 16 experimental units, varying
117 from 0.23 to 0.32 ha per unit. The experiment was designed as randomized blocks, with
118 four repetitions, in a 2 × 2 factorial system with subdivided plots. The main factors were
119 two different grazing intensities (moderate and low) and two stocking methods
120 (continuous and rotational), with subdivided plots representing two summer growing
121 systems (soybean monoculture - soybean/soybean and crop rotation - soybean/maize).

122 During the pasture phase, the area was grazed by **11-month-old** sheep weighing 35
123 ± 4 kg. A variable number of sheep were used following the *put-and-take* technique (Mott
124 and Lucas, 1952) to maintain the recommended grazing intensities. Grazing intensities
125 were defined by forage supply, expressed in kg of dry matter (DM) per 100 kg of live

126 weight (LW) per day: (i) moderate grazing intensity – forage offer equivalent to 2.5 times
127 the forage intake potential of sheep; (ii) low grazing intensity – forage offer equivalent to
128 5.0 times the forage of sheep potential intake. The forage intake potential of lambs
129 according to the National Research Council (1985) is 4.0%, based on DM, low offer
130 equivalent to 10% of the LW and moderate offer of 20% of the LW.

131 The two stocking methods differing by the amount of time the sheep were present
132 in each plot. In the continuous stocking method, the sheep remained in the area during
133 the whole grazing period, while in the rotational, the plots were subdivided and the sheep
134 were rotated, remaining approximately two days in each pasture range. This period was
135 calculated in function of live ryegrass leaves and accumulated degree days.

136 The grass length was monitored every fifteen days using a graduated *sward stick*
137 (Barthram, 1985) with 30 random points measured per experimental unit during each
138 pasture cycle, from 2003 to 2008. After 2008, 150 random points were measured
139 randomly to allow better estimates. Different load adjustment was adopted to maintain a
140 forage supply of 2.5 and 5.0 times the consumption potential. At the end of each pasture
141 cycle, the sheep were removed, and the area desiccated with *glyphosate* herbicide in
142 preparation for the subsequent summer sowing. The average annual fertilization applied
143 during the 14-yr experimental period was 150 kg N ha⁻¹, 30 kg P ha⁻¹ and 50 kg K ha⁻¹,
144 fertilized during the pasture cycle. The season and annual fertilization rates can be found
145 in Alves et al. (2019). The maize was fertilized with rates of 110 and 150 kg N ha⁻¹,
146 respectively, only in 2009/2010 and 2011/2012 growing seasons.

147 In the cropping phase, each plot was divided into two subplots. Each subplot was
148 divided in two crop systems: monoculture - soybean/soybean and crop rotation -
149 soybean/maize (50%-50%), both under no-tillage. In the first summer cycle soybean
150 (*Glycine max*) was sown in the whole experimental area. In the second cycle soybean was

151 sown in half the subplot and maize in the other half (subplots monoculture and crop
152 rotation, respectively), with 45 cm between lines and a population of 280,000 plants ha⁻¹. Soybean and maize were sown from October to November.

154

155 2.2. Crop yield

156 Soybean yield was evaluated over five crop/growing seasons (2003/2004,
157 2004/2005, 2006/2007, 2010/2011 and 2014/2015). The maize yield was evaluated over
158 six crop/growing seasons (2005/2006, 2007/2008, 2009/2010, 2011/2012, 2013/2014 and
159 2015/2016).

160 Yield was evaluated by collecting from five random points in each subplot, each
161 point with two linear meters, totalling 4.5 m². After collection, the samples were dried
162 and the grain yield presented 130 g kg⁻¹ of moisture content.

163

164 2.3. The water requirement satisfaction index (WRSI) of the soybean and maize crops

165 The WRSI was calculated from the ratio between real (ET_r) and maximum
166 evapotranspiration (ET_m) of the crop (soybean or maize). When water requirement and
167 supply meet, the WRSI is equal to 1 (ET_r = ET_m). When the ET_r < ET_m, the crop yield
168 may be limited by deficit water stress. The WRSI was calculated for all years from
169 October 15th to March 15th, including the period from sowing to harvesting of the summer
170 crops (soybeans and corn) (**Fig. S1**). For the correlation study between WRSI and crop
171 yield, the reproductive period (stages R1-R6) was used as this period is critical for a good
172 crop yield (Franchini et al. 2012).

173 The values of ET_r and ET_m were determined for the soybean and maize crop
174 cycle. The BIPZON model was used to simulate the crop hydric balance (Forest, 1984).
175 This model allows the input of data from converging variables such as climate (rainfall

176 and average daily temperature); crop (coefficient of the crop K_c); and soil (available water
177 capacity). The available water capacity was estimated considering the least limiting water
178 range, that means soil water content that do not limit plant growth, taking into account
179 field capacity, wilting point, air-filled porosity, and mechanical resistance (Silva et al.,
180 1994). The available water capacity was 60 mm, considering an effective root depth of
181 0.5 m.

182

183 *2.4. Determination of forage production*

184 Above-ground productivity (AGP, Mg ha^{-1}) of the pasture was evaluated in the
185 years 2004, 2005, 2006, 2007, 2010, 2011, 2012, 2015 and 2016. The AGP was calculated
186 by using the accumulated forage mass at the beginning of the grazing period, added to the
187 forage accumulation rate (kg day^{-1}) and multiplied by the number of grazing days, over
188 an average period of 101 ± 9 days.

189 The residual aboveground forage mass (RFM, Mg ha^{-1}) was calculated at the end
190 of the grazing period in the years 2010, 2011, 2012, 2015 and 2016, using subsamples.
191 Samples were collected randomly using a 0.25m^2 metal frame ($0.5\text{ m} \times 0.5\text{ m}$). All the
192 remaining above ground forage, was cut and dried in an oven with air circulation at 65
193 $^{\circ}\text{C}$ for 72 hours. After drying, the material was weighed and the results expressed as Mg
194 ha^{-1} .

195

196 *2.5. Soil sampling and analyses of the C and N content of the soil*

197 The soil was sampled in June, after the soybean harvest and before the ryegrass
198 sowing, because at this time the influence of root exudates or mineralization of biomass
199 from previous crops on the C and N contents in the soil is the lowest (Schieung et al.,
200 2017). The soil was sampled with an auger at the layers 0–5, 5–10, 10–20 and 20–30 cm.

201 The samples were dried in a forced-air oven at 45 °C. The larger lumps broken up, ground
202 and sieved with a 2.0 mm sieve. A 2.0 g subsample was ground and sieved to ≤ 0.100 mm.
203 The soil C and N contents were analysed by dry combustion in a Fisher Scientific
204 FlashEA[®]. Bulk density was measured using the volumetric ring method (Blake and
205 Hartge, 1986), in the 0–10, 10–20 and 20–30 cm layers. Then, the C and N stocks in the
206 0–30 cm layer were calculated by the soil mass method (Ellert and Bettany, 1995). The
207 soil used as the reference was sampled from the treatment with moderate grazing intensity
208 under the continuous stocking method and soybean monoculture. The soil density in the
209 0–10 cm layer was used in the calculation of the C and N stocks in the 0–5 and 5–10 cm
210 layers.

211 Soil C accumulation rates were calculated with the ratio between the C stock of the
212 soil and the soil with the lowest C stock (crop rotation, moderate grazing intensity and
213 continuous stocking method) over the duration of the experiment (14-yr).

214

215 2.6. *Statistical analyses*

216 Statistical analysis was performed with SAS[®] 9.4 software and the results were
217 subjected to a normality analysis by the Shapiro-Wilk test and the homogeneity of
218 variances by the Levene test, both at a significance level of 5%. The results were
219 submitted to ANOVA at a 5% significance level (ANOVA, $P > 0.05$). When significant,
220 the difference between the treatment means was evaluated by the Tukey test, also at 5%.

221 A factorial model with split plots was used for the analysis of soybean yield and
222 RFM. The effects were two stocking methods and two grazing intensities, with the
223 cropping systems subdivided in plots, considering the effects of the block (B), the
224 stocking method (M), grazing intensity (I), cropping system (S), the interactions M*I,
225 M*S, I*S, M*I*S and the year as a repeated measure of time. A factorial model was used

226 for the analysis of maize yield and AGP, considering the B, M, I effects and the M*I
227 interaction, and the year as a repeated measure of time. The factorial model used
228 subdivided sub-plots for the C and N content in the soil, with the soil layer as the
229 subdivided sub-plot, considering the effects B, M, I, S, soil layer (C) and the interaction
230 between M*I, M*S, I*S, M*I*S, M*C, I*C, S*C, M*I*C, M*S*C, I*S*C and M*I*S*C.
231 For the stocks and the accumulation rates of C and N in the soil, considering the effects
232 B, M, I, S and the interaction between M*I, M*S, I*S and M*I*S. In all models, the B
233 effect and its interactions were considered random effects and the other factors were
234 considered fixed effects.

235 The significance of the relationship between C and N content in the soil and C and
236 N inputs by crops and pasture were evaluated using Pearson's correlation coefficients (r)
237 at the 5% level.

238

239 **3. Results**

240 *3.1. Crop and forage production*

241 Soybean yield was not affected by the cropping system (**Tables 1 and 2**). In two
242 (2003/2004 and 2006/2007) of the five harvests evaluated, soybean yield was not affected
243 by stocking method and grazing intensity. In the 2004/2005 season, the adoption of
244 rotational stocking method, favour greater soybean yield in continuous-moderate (30%)
245 and continuous-low (272%) (**Tables 1 and 2**). On the other hand, in the 2010/2011
246 season, lower soybean yield was observed in the continuous-moderate treatment
247 compared to the other treatments. In the 2014/2015 season, independent of the grazing
248 intensity, the average soybean yield observed in rotational stocking method was 48%
249 greater than the continuous stocking method (**Table 2**). The highest soybean yield during

250 the experimental period was observed in the 2014/2015 season, with an average of 3.0
251 Mg ha⁻¹.

252 Maize yield was slightly affected by the stocking methods and grazing intensities.
253 Maize yield was low throughout the evaluation period, ranging from 1.9 Mg ha⁻¹ in the
254 2007/2008 season to 7.7 Mg ha⁻¹ in the 2015/2016 season (**Fig. 1**). Although maize
255 showed a tendency for higher yields at low grazing intensity, this result was significant
256 only in the 2015/2016 season, which also had the highest maize yields compared to other
257 seasons (**Fig. 1**). In the 2015/2016 season, grain yield in low grazing intensity was 40%
258 higher (2.4 Mg ha⁻¹) than in moderate intensity.

259 **Fig. 2A** presents the relationship between WRSI and maize yield under different
260 grazing intensities (moderate and low). At low grazing intensity, for every 0.1 unit
261 increase in WRSI, maize yield increased by 0.97 Mg ha⁻¹, *versus* 0.64 Mg ha⁻¹ at moderate
262 grazing intensity. In **Fig. 2B**, the relationship between WRSI and soybean yield is
263 presented **for the** combination of stocking method and grazing intensity: continuous-low,
264 continuous-moderate, rotational-low and rotational-moderate. Under continuous stocking
265 method with low grazing intensity, the increase of 0.1 unit increase in WRSI favoured the
266 **increase** of soybean yield by 0.24 Mg ha⁻¹ *versus* 0.20 Mg ha⁻¹ under continuous stocking
267 with moderate grazing intensity. The relationship was not significant under rotational
268 stocking.

269 AGP ranged from 4.8 to 16.8 Mg ha⁻¹ and was affected by grazing intensity (**Fig.**
270 **3**). Over the experimental period, AGP in low intensity grazing (11.1 Mg ha⁻¹) was 32%
271 higher than in moderate grazing intensity (8.4 Mg ha⁻¹) (**Fig. 3**). RFM aboveground was
272 affected by grazing intensity and cropping system over the experimental period (**Table**
273 **1**). RFM mean was 7% higher in soybean monoculture (3.1 Mg ha⁻¹) than in crop rotation

274 (2.8 Mg ha⁻¹) (**Fig. 4**). Regarding grazing intensities, low grazing intensity (3.4 Mg ha⁻¹)
275 resulted in 28% more residue than moderate intensity (2.7 Mg ha⁻¹) (**Fig. 4**).
276

277 3.2. Soil C and N content and stocks

278 C and N content in the **surface** soil layers (0–5 and 5–10 cm) were affected by
279 cropping systems, as well as grazing intensities (**Table 1 and Fig. 5**). In the 0–10 cm
280 layer, the average C concentration under low grazing intensity was 20% higher (14.1 g
281 kg⁻¹) than under moderate grazing intensity (11.8 g kg⁻¹) (**Fig. 5B**). Using the average of
282 the two layers (0–5 and 5–10 cm), the highest N concentration **was** observed under low
283 grazing intensity (1.5 g kg⁻¹) compared to moderate grazing intensity (1.2 g kg⁻¹) (**Fig.**
284 **5D**). Greater C and N concentration in 0–5 and 5–10 cm soil layers was observed in
285 soybean monoculture, averaging in the 0–10 cm layer 14.3 and 1.6 g kg⁻¹ of C and N,
286 respectively, which is around 22 and 27% greater than **under the** crop rotation system
287 (**Fig. 5A and 5C**).

288 C and N stocks in the 0–30 cm soil layer ranged from 39 to 45 Mg ha⁻¹ and 3.9 to
289 4.9 Mg ha⁻¹, respectively, and were affected by cropping system and grazing intensities.
290 Higher C and N stock in 0–30 cm soil layer was observed in soybean monoculture (45
291 and 5 Mg ha⁻¹, respectively) compared to crop rotation system (39 and 4 Mg ha⁻¹,
292 respectively) (**Table 4**). This led to significant accumulation rates of 500 kg C ha⁻¹ yr⁻¹
293 and 78 kg N ha⁻¹ yr⁻¹ in the soil under soybean monoculture (**Table 4**). In addition, C and
294 N stock was 11 and 9% higher, respectively, under low grazing intensity compared to
295 moderate grazing. Soil accumulation rates **were** 500 kg C ha⁻¹ yr⁻¹ and 57 kg N ha⁻¹ yr⁻¹
296 under low intensity and 200 kg C ha⁻¹ yr⁻¹ and 27 kg N ha⁻¹ yr⁻¹ under moderate grazing
297 intensity, **respectively** (**Table 4**).

298 Significant relationships between the input of C (**Fig. 6A**) and N (**Fig. 6B**) via
299 crop residues from each cropping system, monoculture and crop rotation, and the C stock

300 were observed. Each 1000 kg of C annually inputted via above-ground biomass, the C
301 stock increased by 14.5 kg ha⁻¹ in soybean monoculture, versus 4.5 kg ha⁻¹ in the crop
302 rotation system. For N inputs, each 10 kg of N annually inputted via above-ground
303 biomass, the N stock increased by 0.53 Mg ha⁻¹ in soybean monoculture, versus 0.30 Mg
304 ha⁻¹ in the crop rotation system.

305

306 **4. Discussion**

307 Our study showed that low grazing intensities favour significant increases in soil
308 C and N stocks in subtropical environments, which corroborate to previous studies (Souza
309 et al., 2009; Assmann et al., 2014). In our study, considering the 0–30 cm soil layer, the
310 highest rates of C and N accumulation were observed in the systems with low intensity
311 grazing and soybean monoculture (**Table 4**). This higher soil accumulation is associated
312 with higher C and N input via crop residues at low compared to moderate grazing intensity
313 (annual difference 2.7 Mg ha⁻¹), as demonstrated by the higher AGP (**Table 3 and Fig.**
314 **3**). This higher C and N input in low grazing intensity is due to lower forage intake by the
315 lower number of sheep, leading consequently to higher AGP and RFM (**Fig. 3 and 4**).

316 Soybean monoculture promoted greater increase in soil C when compared to crop
317 rotation. Although the relationship between soil C stock and C input was significant in
318 both soybean monoculture and crop rotation systems (**Fig. 6A**), for each kg of C added
319 annually via plant residues, there was an increase of 14.5 kg C ha⁻¹ under soybean
320 monoculture and only 4.5 kg C ha⁻¹ under crop rotation. In addition, N input via residues
321 affected soil C stocks under both cultivation systems. Each kg of N added annually via
322 plant residues generated greater increase under soybean monoculture (530 kg C ha⁻¹) than
323 under crop rotation (300 kg C ha⁻¹). (**Fig. 6B**). Thus, our results suggest that residue
324 quality was the main driver for soil C accumulation, as observed by Manzoni et al.

325 (2008), which is possibly associated to greater efficiency of microorganisms in stabilizing
326 C from labile (higher N content) plant residue into microbial residues that later might be
327 stabilized in organo-mineral association (Cotrufo et al., 2013, 2015; Veloso et al., 2019,
328 2020).

329 The effect of higher N supply for forage production in succession, is probably due
330 to the high biological N fixation which is used to supply the needs of the soybean crop,
331 therefore reducing the dependence on N from mineralization of the SOM (Ciampitti and
332 Salvagiotti, 2018). The higher N supply available for the subsequent pasture cultivation
333 in the soybean monoculture system is associated to both lower C/N ratio and higher N
334 input through crop residues to the soil, favouring then higher RFM compared to maize.
335 Varvel and Wilhelm (2003) also observed that the soybean crop could contribute larger
336 quantities of N to subsequent crops, giving better conditions for the development of
337 pasture in contrast to maize. In addition, the absence of N fertilization under maize
338 (except for the 2009/2010 and 2011/2012 seasons), probably contributed to high N
339 immobilization, negatively affecting the initial development of the successive hibernal
340 pasture (Campos, 2015) when compared to the soybean monoculture system.

341 Mainly due to the frequent droughts (as indicated by the low WRSI observed
342 during the majority of the crop seasons - **Fig. 2**), the average C input over the experimental
343 period was 2.4 Mg ha⁻¹ in the crop rotation system (**Table 3**), very similar to that observed
344 in the soybean monoculture. Although maize adoption in cropping systems in subtropical
345 environments is a viable alternative with a potential for a C input higher than 4 Mg ha⁻¹
346 (Veloso et al., 2018), the C input by maize in this study was much lower than expected.

347 The greater maize grain yield after low intensity grazing in 2015/2016 season
348 (**Fig. 1**) is possibly related to the higher C and N soil content in this system obtained in
349 the long-term compared to grazing at moderate intensity (**Table 4**). It can also be

350 explained by the higher WRSI, which showed a linear relationship with yield (**Fig. 2**).
351 Thus, the system using low grazing intensity, which had a higher capacity to supply the
352 nutritional needs, especially N due to the larger soil stock, was more favoured under
353 superior water supply conditions. (**Fig. 2**).

354 The soybean grain yield did not respond positively to increases in soil N levels
355 caused by the adoption of low grazing intensities. (**Table 2**). This is mainly due to the
356 fact that the treatments in this study do not affect other soil chemical properties (Alves et
357 al., 2019) and because soybeans obtain much of their N requirement from biological N
358 fixation, depending less on N soil supply (Ciampitti and Salvagiotti, 2018) in contrast to
359 maize. However, soybean yield was affected by the different pasture management
360 methods and grazing intensities (**Table 2**). The rotational method, independent of the
361 grazing intensity, resulted in higher soybean yield when compared to the continuous
362 method adopted in the 2004/2005 and 2014/2015 seasons (**Table 2**). The higher soybean
363 yield in the rotational stocking method can be explained with the fact that continuous
364 grazing can affect spatial patterns of the soil attributes, increasing spatial heterogeneity
365 of the pastures and the environment (Laca, 2009, Auerswald et al., 2010). As the animals
366 circulate freely selecting grazing areas, manure is deposited unevenly influencing the
367 concentration of nutrients in the soil (McNaughton, 1985; Augustine & Frank, 2001),
368 with the highest concentrations being found near to the rest areas, shade and water troughs
369 (Dennis et al. 2012; Dubeux et al., 2014). This does not happen using the rotational
370 stocking method, where the animals are placed in grazing ranges that rotate in space and
371 time, favouring the better distribution of manure within the grazing range (Peterson and
372 Gerrish, 1996), and achieving better control of spatial nutrient cycling and soil fertility.

373

374 **5. Conclusions**

375 The aboveground productivity of pasture and the maize yield are higher in the
376 system with low grazing intensity during the pasture phase. In contrast, soybean presented
377 higher yields when the rotational pasture method was used in the winter, regardless of the
378 grazing intensity. The residual forage mass in the pasture phase was favoured by the
379 soybean monoculture system in the summer.

380 Low grazing intensity in the pasture phase favoured the increase in the C and N
381 stocks in the soil. The pasture management method, continuous or rotational, did not
382 affect the accumulation of C and N in the soil. The higher quality of soybean crop residues
383 and similar annual input of C determined higher soil C and N stocks, in comparison to
384 the rotation soybean/maize. Thus, our results provided field-based evidence that crop
385 residues with greater N content, favoured soil C accumulation. Maize yield was low in
386 most of the seasons due to the low water requirement satisfaction index, reducing the
387 potential for the accumulation of C and N in the soil under rotation soybean/maize.

- 389 Alves, L. A., Denardin, L. G. O., Martins, A. P., Anghinoni, I., Carvalho, P. C. F.,
390 Tiecher, T., 2019. Soil acidification and P, K, Ca and Mg budget as affected by sheep
391 grazing and crop rotation in a long-term integrated crop-livestock system in southern
392 Brazil. *Geoderma* 351, 197-208. <https://doi.org/10.1016/j.geoderma.2019.04.036>
- 393 Assmann, J. M., Anghinoni, I., Martins, A. P., de Andrade, S. E. V. G., Cecagno, D.,
394 Carlos, F. S., Carvalho, P. C. F., 2014. Soil carbon and nitrogen stocks and fractions in a
395 long-term integrated crop–livestock system under no-tillage in southern Brazil. *Agr.*
396 *Ecosyst. Environ.* 190, 52-59. <https://doi.org/10.1016/j.agee.2013.12.003>
- 397 Auerswald, K., Mayer, F., Schnyder, H., 2010. Coupling of spatial and temporal pattern
398 of cattle excreta patches on a low intensity pasture. *Nutr. Cycl. Agroecosys.* 88, 275-288.
399 <https://10.1007/s10705-009-9321-4>
- 400 Augustine, D. J., Frank, D. A., 2001. Effects of migratory grazers on spatial heterogeneity
401 of soil nitrogen properties in a grassland ecosystem. *Ecology* 82, 3149-3162.
402 <https://10.2307/2679841>
- 403 Barthram, G.T., 1985. Experimental Techniques: The HFRO Sward Stick. The Hill
404 Farming Research Organization/Biennial Report. HFRO, Penicuik, pp. 29-30.
- 405 Bayer, C., Lovato, T., Dieckow, J., Zanatta, J. A., Mielniczuk, J., 2006. A method for
406 estimating coefficients of soil organic matter dynamics based on long-term experiments.
407 *Soil Till. Res.* 91(1-2), 217-226. <https://doi.org/10.1016/j.still.2005.12.006>
- 408 Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), *Methods of Soil*
409 *Analysis, Part 1. Physical and Mineralogical Methods.* ASA/SSSA, Madison, pp. 363–
410 382. <https://doi:10.2136/sssabookser5.1.2ed.frontmatter>
- 411 Campos, B. M., 2015. Estabelecimento do azevém anual em sistemas integrados de
412 produção agropecuária: implicações do resíduo das lavouras de soja e milho. 48 f.
413 Dissertação (Mestrado) - Pós-Graduação em Agronomia – Produção Vegetal.
414 Universidade Federal do Paraná, Curitiba - PR.
- 415 Carvalho, P. C. F., Anghinoni, I., Moraes, A., Souza, E. D., Sulc, R. M., Lang, C. R.,
416 Flores, J. P. C, Lopes, M. L. R., Silva, J. L. S., Conte, O., Wesp, C. L., Levien, R.,
417 Fontaneli, R. S., Cimelio Bayer, C., 2010. Managing grazing animals to achieve nutrient
418 cycling and soil improvement in no-till integrated systems. *Nutr. Cycl. Agroecosys.* 88(2),
419 259-273. <https://doi.org/10.1007/s10705-010-9360-x>
- 420 CFS-RS/SC – Comissão de Fertilidade Do Solo - RS/SC, 1995. *Recomendações de*
421 *adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina*, 3 ed.
422 SBCS - Núcleo Regional Sul/EMBRAPA-CNPT, Passo Fundo, 224 p.
- 423 Chen, J., Heiling, M., Resch, C., Mbaye, M., Gruber, R., Dercon, G., 2018. Does maize
424 and legume crop residue mulch matter in soil organic carbon sequestration? *Agr. Ecosyst.*
425 *Environ.* 265, 123-131. <https://doi.org/10.1016/j.agee.2018.06.005>
- 426 Ciampitti, I. A., Salvagiotti, F., 2018. New Insights into Soybean Biological Nitrogen
427 Fixation. *Agron. J.* 110(4), 1185. <https://10.2134/agronj2017.06.0348>

- 428 CONAB, 2019. Observatório Agrícola: Acompanhamento da Safra Brasileira de Grãos,
429 6 (6) - safra 2018/19. Download pdf from website:
430 [https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc](https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc6c0c7f53522a)
431 [6c0c7f53522a](https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc6c0c7f53522a)
- 432 Cotrufo, M. F., Wallenstein, M. D., Boot, C. M., Deneff, K., Paul, E., 2013. The Microbial
433 Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition
434 with soil organic matter stabilization: do labile plant inputs form stable soil organic
435 matter? *Glob. Change Biol.* 19(4), 988-995. <https://doi.org/10.1111/gcb.12113>
- 436 Cotrufo, M. F., Soong, J. L., Horton, A. J., Campbell, E. E., Haddix, M. L., Wall, D. H.,
437 Parton, W. J., 2015. Formation of soil organic matter via biochemical and physical
438 pathways of litter mass loss. *Nat. Geosci.* 8(10), 776-781. <https://10.1038/NNGEO2520>
- 439 CQFS-RS/SC – Comissão De Química E Fertilidade Do Solo - RS/SC, 2004. Manual de
440 adubação e calagem para os Estados do Rio Grande do Sul e Santa Catarina. Porto Alegre:
441 SBCS - Núcleo Regional Sul/EMBRAPA-CNPT, 400 p.
- 442 Dennis, S.J., Moir, L. J., Cameron, K. C., Edwards, G. R., Di, H. J., 2012. Measuring
443 excreta patch distribution in grazed pasture through low-cost image analysis. *Grass*
444 *Forage Sci.* 68:378–385. <https://10.1111/gfs.12000>
- 445 Dubeux, J. C. B., Sollenberger, L. E., Vendramini, J. M. B., Interrante, S. M., Lira, M.
446 A., 2014. Stocking Method, Animal Behavior, and Soil Nutrient Redistribution: How are
447 They Linked? *Crop Sci.* 54(5), 2341-2350. <https://10.2135/cropsci2014.01.0076>
- 448 Ellert, B. H., Bettany, J. R., 1995. Calculation of organic matter and nutrients stored in
449 soils under contrasting management regimes. *Can. J. Soil Sci.* 75(4), 529-538.
450 <https://doi.org/10.4141/cjss95-075>
- 451 FAO, I, 2006. World reference base for soil resources 2006. In: World Soil Resources
452 Reports Nr. 103. Rome, Italy. Download pdf from website: [https://www.fao.org/3/a-](https://www.fao.org/3/a-a0510e.pdf)
453 [a0510e.pdf](https://www.fao.org/3/a-a0510e.pdf)
- 454 Forest, F., 1984. Simulation du bilan hydrique des cultures pluviales. In: Présentation et
455 utilisation du logiciel BIP, Irat-Cirad, Montpellier, p. 63.
- 456 Franchini, J. C., Debiassi, H., Junior, A. A. B., Tonon, B. C., Farias, J. R. B., de Oliveira,
457 M. C. N., Torres, E., 2012. Evolution of crop yields in different tillage and cropping
458 systems over two decades in southern Brazil. *Field Crop. Res.* 137, 178-185.
459 <https://doi.org/10.1016/j.fcr.2012.09.003>
- 460 Ghosh, S., Wilson, B. R., Mandal, B., Ghoshal, S. K., Growns, I., 2010. Changes in soil
461 organic carbon pool in three long-term fertility experiments with different cropping
462 systems and inorganic and organic soil amendments in the eastern cereal belt of India.
463 *Soil Res.* 48(5), 413-420. <https://doi.org/10.1071/SR09089>
- 464 Kottek, M., Grieser, J., Beck, C., Rudolf, B. and Rubel, F., 2006. World map of the
465 Köppen-Geiger climate classification updated. *Meteorol. Z.* 15(3), 259-263.
466 <https://doi.org/10.1177/0941-294820060130>
- 467 Laca, E. A., 2009. New Approaches and Tools for Grazing Management. *Rangeland Ecol.*
468 *Mana.* 62(5), 407-417. <http://doi.org/10.2111/08-104.1>.

- 469 Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food
470 security. *Science*. 304(5677), 1623-1627. <https://10.1126/science.1097396>
- 471 Luz, F. B., Silva, V. R., Mallmann, F. J. K., Pires, C. A. B., Debiassi, H., Franchini, J. C.,
472 Cherubin, M. R., 2019. Monitoring soil quality changes in diversified agricultural
473 cropping systems by the Soil Management Assessment Framework (SMAF) in southern
474 Brazil. *Agr. Ecosyst. Environ* 281, 100-110. <https://doi.org/10.1016/j.agee.2019.05.006>
- 475 Manzoni, S., Jackson, R. B., Trofymow, J. A., Porporato, A., 2008. The global
476 stoichiometry of litter nitrogen mineralization. *Science*. 321(5889), 684-686.
477 <https://10.1126/science.1159792>
- 478 McNaughton S. J.; 1985. Ecology of grazing ecosystem: the Serengeti. *Ecol. Monogr.* 55,
479 259-295. <http://dx.doi.org/10.2307/1942578>
- 480 Moraes, A., Carvalho, P.C.F., Anghinoni, I., Lustosa, S.B.C., Costa, S.E.V.G.A.,
481 Kunrath, T.R., 2014. Integrated crop-livestock systems in the Brazilian subtropics. *Eur.*
482 *J. Agron.* 57 (4–9), 2014. <https://doi.org/10.1016/j.eja.2013.10.004>
- 483 Mott, G.O., Lucas, H.L., 1952. The design conduct and interpretation of grazing trials
484 on cultivated and improved pastures. In: *International Grassland Congress*, 6, 1952,
485 Pennsylvania. *Proceeding. State College, Pennsylvania*, pp. 1380–1395.
- 486 National Research Council, 1985. *Nutrient Requirement of Sheep*, 6th ed. National
487 Academy of Science, Washington (99p).
- 488 Reeder, J. D., Schuman, G. E., 2002. Influence of livestock grazing on C sequestration in
489 semi-arid mixed-grass and short-grass rangelands. *Environ. Pollut.* 116(3), 457-463.
490 [https://doi.org/10.1016/S0269-7491\(01\)00223-8](https://doi.org/10.1016/S0269-7491(01)00223-8)
- 491 Peterson, P.R., and J.R. Gerrish., 1996. Grazing systems and spatial distribution of
492 nutrients in pastures: Livestock management considerations. In: C.A. Roberts, editor,
493 *Nutrient cycling in forage systems*. 203-212.
- 494 Sá, J. C. M, Lal, R., Cerri, C. C., Lorenz, K., Hungria, M., Carvalho, P. C. F., 2017. Low-
495 carbon agriculture in South America to mitigate global climate change and advance food
496 security. *Environ. Int.* 98, 102-112. <https://doi.org/10.1016/j.envint.2016.10.020>
- 497 Schiedung, H., Bornemann, L., Gerhard, W. E. L. P., 2017. Seasonal variability of soil
498 organic carbon fractions under arable land. *Pedosphere* 27(2), 380-386.
499 [https://doi.org/10.1016/S1002-0160\(17\)60326-6](https://doi.org/10.1016/S1002-0160(17)60326-6)
- 500 Silva, A. P., Kay, B. D., Perfect, E., 1994. Characterization of the least limiting water
501 range of soils. *Soil Sci. Soc. Am. J.* 58(6), 1775-1781.
502 <https://10.2136/sssaj1994.03615995005800060028x>
- 503 Souza, E. D. D., Costa, S. E. V. G. D. A., Anghinoni, I., Carvalho, P. C. D. F., Andrighetti,
504 M. H., Cao, E. G., 2009. Estoques de carbono orgânico e de nitrogênio no solo em sistema
505 de integração lavoura-pecuária em plantio direto, submetido a intensidades de pastejo.
506 *Rev. Bras. Cienc. Solo.* 33(6), 1829-1836. <https://dx.doi.org/10.1590/S0100-06832009000600031>
507

- 508 Steduto, P., Hsiao, T. C., Fereres, E., Raes, D., 2012. Crop Yield Response to Water. FAO
509 Irrigation and Drainage Paper Nr. 66. Rome, Italy. Download pdf from website:
510 <https://www.fao.org/docrep/016/i2800e/i2800e00.htm>
- 511 Varvel, G. E., Wilhelm, W. W., 2003. Soybean Nitrogen Contribution to Corn and
512 Sorghum in Western Corn Belt Rotations. *Agron. J.* 95, 1220-1225.
513 <https://10.2134/agronj2003.1220>
- 514 Veloso, M.G., Angers, D.A., Tiecher, T., Giacomini, S., Dieckow, J., Bayer, C., 2018.
515 High carbon storage in a previously degraded subtropical soil under no-tillage with
516 legume cover crops. *Agr. Ecosyst. Environ.* 268, 15-23.
517 <https://dx.doi.org/10.1016/j.agee.2018.08.024>
- 518 Veloso, M. G., Cecagno, D., Bayer, C., 2019. Legume cover crops under no-tillage favor
519 organomineral association in microaggregates and soil C accumulation. *Soil Till. Res.*
520 190, 139-146. <https://doi.org/10.1016/j.still.2019.03.003>
- 521 Veloso, M. G., Angers, D. A., Chantigny, M. H., Bayer, C., 2020. Carbon accumulation
522 and aggregation are mediated by fungi in a subtropical soil under conservation
523 agriculture. *Geoderma*, 363, 114159. <https://doi.org/10.1016/j.geoderma.2019.114159>

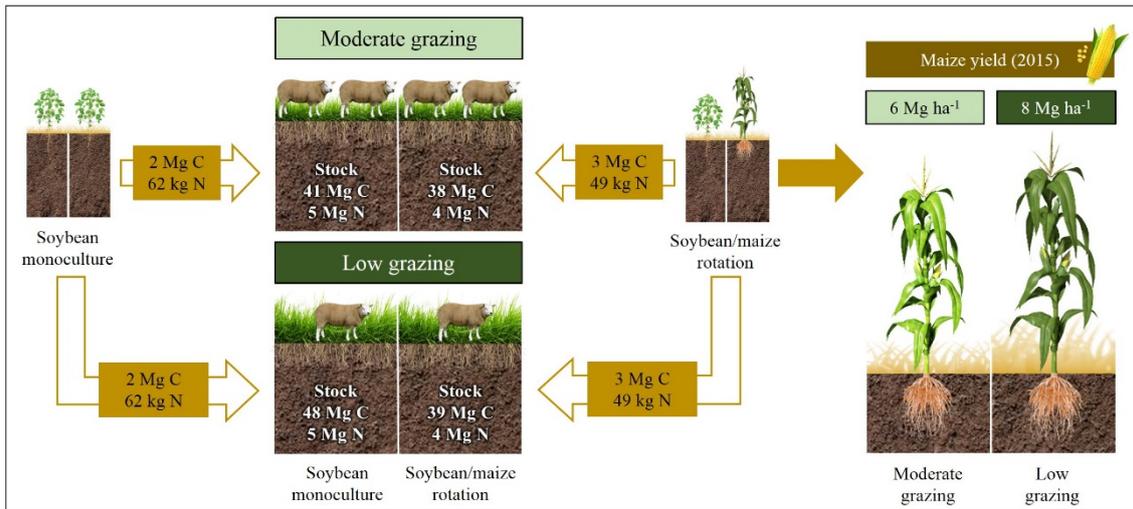
Highlights

Grazing intensity and stocking method effect on soil C and N stock were evaluated

Low grazing intensity resulted in higher soil C and N stocks in long-term

Residues quality (C : N ratio) played a key role in soil C accumulation

Higher soil N stocks in low grazing intensity favored maize yield



Graphical Abstract. Schematic map of carbon and nitrogen inputs in the soil via crop and pasture residues and the respective carbon and nitrogen stocks in the 0–30 cm soil layer influencing maize yield in Southern Brazil.

1 **The effect of crop rotation and sheep grazing management on plant**
2 **production and soil C and N stocks in a long-term integrated crop-**
3 **livestock system in Southern Brazil**

4
5 Lucas Aquino Alves^{a,*}, Luiz Gustavo de Oliveira Denardin^a, Amanda Posselt Martins^b,
6 Cimélio Bayer^b, Murilo Gomes Veloso^b Carolina Bremm^c, Paulo César de Faccio
7 Carvalho^c, Debora Rubin Machado^d, Tales Tiecher^{b,*}

8
9 ^a *Graduate Program in Soil Science, Interdisciplinary Research Group on Environmental*
10 *Biogeochemistry (IRGEB), Federal University of Rio Grande do Sul, Bento Gonçalves Avenue 7712,*
11 *91540-000, Porto Alegre, RS, Brazil*

12 ^b *Department of Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue 7712,*
13 *91540-000, Porto Alegre, RS, Brazil*

14 ^c *Animal Science Research Program, Federal University of Rio Grande do Sul, Bento Gonçalves Avenue*
15 *7712, 91540-000, Porto Alegre, RS, Brazil*

16 ^d *Graduate Program in Animal Science, Grazing Ecology Research Group, Federal University of Rio*
17 *Grande do Sul, Bento Gonçalves Avenue 7712, 91540-000, Porto Alegre, RS, Brazil*

18
19 * Corresponding author

20 E-mail address: lucas.aquino@ufrgs.br (L. A. Alves)

21 E-mail address: tales.tiecher@ufrgs.br (T. Tiecher)

22 **The effect of crop rotation and sheep grazing management on plant**
23 **production and soil C and N stocks in a long-term integrated crop-**
24 **livestock system in Southern Brazil**

25
26 **Abstract**

27 Integrated crop-livestock systems (ICLS) conducted under no-tillage have been shown to
28 favour the accumulation of carbon (C) and nitrogen (N) in soil. In that systems, however,
29 C and N accumulation in soil might depend on pasture management and the type of
30 crop rotation used. The objective of this study was to evaluate the impact of two stocking
31 methods (continuous and rotational) and two sheep grazing intensities (moderate and low)
32 on winter pasture and the effect of summer crop rotation (soybean and/or maize) on crop
33 yield and C and N stocks in an Acrisol after 14-yr under experimental conditions. The
34 evaluated ICLS was set up for grain yield in the summer crop phase and for sheep meat
35 production in the winter pasture phase. Pasture production, soybean and corn yield were
36 evaluated throughout the experimental period. After 14-yr, the soil was sampled at the 0-
37 5, 5-10, 10-20 and 20-30 cm layers to evaluate the content and stock of C and N. Higher
38 C and N contents in soil superficial layers (0–5 and 5–10 cm) were observed under low
39 grazing intensity in winter and soybean monoculture in summer. The C and N stocks in
40 0-30 cm soil layer ranged between 39 and 45 Mg C ha⁻¹ and 4 and 5 Mg N ha⁻¹,
41 respectively. C and N stocks in the soil were significantly related to N added through the
42 residues of pasture and summer crop. This positive relationship is possibly explained by
43 the higher efficiency of microbes in using crop residues enriched in N with posterior
44 stabilization of microbial residues through organo-mineral association in the soil. The
45 higher content and stocks of C and N associated with low intensity grazing favoured a
46 higher maize yield (40%) compared to moderate grazing intensity in the 2015/2016
47 season. According to our results, the accumulation of C and N in the soil under ICLS
48 involving low grazing intensity in the winter and soybean monoculture in the summer
49 was related to the N added/recycled by the soybean and by the hibernal pasture.

50
51 **Keywords:** Grazing intensities, Stocking methods, Soybean, Maize, Annual ryegrass.

52 1. Introduction

53 **Soil** organic matter (SOM) influences the chemical, physical and biological
54 conditions in the soil as well as **determining** its productive capacity (Ghosh et al., 2010;
55 Lal, 2004). The SOM content is affected by soil management, **especially no-tillage**, and
56 crop systems with high input of plant residues **have been shown as strategies to favour**
57 **SOM accumulation** (Bayer et al., 2006; Veloso et al., 2018). In addition **to quantity, the**
58 residues **with better** quality **(greater N content) may result** in a greater efficiency of
59 substrate use by the microbiota and **contributing** to accumulation of C and N in the soil
60 (Cotrufo et al., 2013; 2015).

61 Integrated crop-livestock systems (ICLS) **are defined as systems in which there is**
62 **temporary alternation or rotation of pastures and crops** in the same area **over time** (Moraes
63 et al., 2014), contributing to the accumulation of C and N in the soil (Sá et al., 2017; Luz
64 et al., 2019). C and N accumulation is dependent on the stocking method, grazing
65 intensity in the pasture phase and on the choice of summer crops (Carvalho et al., 2010).
66 Results have highlighted the importance of the intensity and the method of animal grazing
67 during hibernal grazing on the accumulation of SOM, which is largely related to the
68 impact of grazing intensity on root system development (Reeder and Schuman, 2002).
69 **However, there is a lack of information regarding the impact of ICLS with different**
70 **production management systems on soil C and N stocks in subtropical environments.**

71 Among the commercial crops utilized during summer in the subtropics, soybean
72 stands out for its large cultivated area, currently estimated at 35.8 million hectares in
73 Brazil, of which 11.9 million are cultivated in three southern states (Paraná, Santa
74 Catarina and Rio Grande do Sul) (CONAB, 2019). The soybean **residue has** low C/N
75 ratio, **that in turn, may increase N availability due to lower soil immobilization by**
76 **microorganisms and, therefore, favour the development of pasture after soybeans**

77 (Campos, 2015). On the other hand, the insertion of maize into crop rotation with
78 soybeans propitiates a greater quantity of plant residues but with a lower quality (higher
79 C/N ratio) compared to soybeans alone (Chen et al., 2018). In subtropical Brazil, maize
80 cultivation is less attractive for local farmers due to the frequent occurrence of water
81 deficits that impact more strongly maize yield, due to its higher sensitivity to water deficit
82 mainly at the flowering stage compared to soybeans (Steduto et al., 2012).

83 Thus, there is a need for results that could guide the impact of the stocking method,
84 grazing intensity in the pasture phase and the crops adopted in the cropping phase on soil
85 C and N stocks and the crops yield. Therefore, this study was aimed to evaluate the impact
86 of grazing (stocking method and grazing intensity) in hibernal pasture and cash crops
87 (monoculture of soybean, and crop rotation of soybean and maize) in the cropping phase
88 on soil C and N stocks, pasture production, soybean and maize yield in the Brazilian
89 subtropics. The study was conducted over 14-yr in an ICLS with grain and sheep-meat
90 production in an Acrisol in the Brazilian subtropics.

91

92 **2. Material and methods**

93 *2.1. Description of the experiment*

94 A long-term study was conducted using an ICLS implanted in 2003, in the
95 Experimental Agronomic Station of the Federal University of Rio Grande do Sul, in
96 Eldorado do Sul county, Rio Grande do Sul state, Brazil (latitude 30°05'S, longitude
97 51°39'O, altitude 46 m). The local climate is classified as subtropical humid (Cfa)
98 according to the Köppen classification (Kottek et al., 2006). The average annual rainfall
99 over the 14-yr experimental period ranged between 1200 and 2000 mm, with an average
100 annual temperature of 19 °C.

101 The soil was classified as a sandy clay loam Acrisol (FAO, 2006). At the
102 beginning of the experiment, the 0-10 cm soil layer presented organic C content of 17 g
103 kg⁻¹, pH-water (1:1 soil/water ratio) of 5.3; exchangeable aluminium (Al), calcium (Ca)
104 and magnesium (Mg) (KCl 1.0 mol L⁻¹) of 0.3, 2.2 and 1.2 cmol_c kg⁻¹, respectively;
105 available phosphorus (P) and potassium (K) (Mehlich 1) of 10 and 135 mg kg⁻¹,
106 respectively; base and Al saturation of 51% and 8%, respectively.

107 Prior to the experiment, the area was natural grassland of the Pampa Biome, with
108 exotic species in the winter, such as ryegrass (*Lolium multiflorum*). The area was
109 desiccated with glyphosate herbicide and limestone was applied (1.0 Mg ha⁻¹) to raise the
110 soil pH (in water) in the 0-10 cm soil layer to 6.0.

111 At the beginning of the experimental period, the area was fertilized with 18 kg P
112 ha⁻¹ and 33 kg K ha⁻¹, which is the amount of fertilizer needed for an expected soybean
113 yield of 3.0 Mg ha⁻¹ (CFS-RS/SC, 1995, CQFS-RS/SC, 2004). Almost every year,
114 ryegrass was sown at a density of 32 kg ha⁻¹ in the autumn-winter period and fertilized
115 with nitrogen split in two applications, of 150 kg N ha⁻¹ as urea.

116 The experimental area of 4.5 ha was divided into 16 experimental units, varying
117 from 0.23 to 0.32 ha per unit. The experiment was designed as randomized blocks, with
118 four repetitions, in a 2 × 2 factorial system with subdivided plots. The main factors were
119 two different grazing intensities (moderate and low) and two stocking methods
120 (continuous and rotational), with subdivided plots representing two summer growing
121 systems (soybean monoculture - soybean/soybean and crop rotation - soybean/maize).

122 During the pasture phase, the area was grazed by 11 month-old sheep weighing 35
123 ± 4 kg. A variable number of sheep were used following the *put-and-take* technique (Mott
124 and Lucas, 1952) to maintain the recommended grazing intensities. Grazing intensities
125 were defined by forage supply, expressed in kg of dry matter (DM) per 100 kg of live

126 weight (LW) per day: (i) moderate grazing intensity – forage offer equivalent to 2.5 times
127 the forage intake potential of sheep; (ii) low grazing intensity – forage offer equivalent to
128 5.0 times the forage of sheep potential intake. The forage intake potential of lambs
129 according to the National Research Council (1985) is 4.0%, based on DM, low offer
130 equivalent to 10% of the LW and moderate offer of 20% of the LW.

131 The two stocking methods differed by the amount of time the sheep were present
132 in each plot. In the continuous stocking method, the sheep remained in the area during
133 the whole grazing period, while in the rotational, the plots were subdivided and the sheep
134 were rotated, remaining approximately two days in each pasture range. This period was
135 calculated in function of live ryegrass leaves and accumulated degree days.

136 The grass length was monitored every fifteen days using a graduated *sward stick*
137 (Barthram, 1985) with 30 random points measured per experimental unit during each
138 pasture cycle, from 2003 to 2008. After 2008, 150 random points were measured
139 randomly to allow better estimates. Different load adjustment was adopted to maintain a
140 forage supply of 2.5 and 5.0 times the consumption potential. At the end of each pasture
141 cycle, the sheep were removed, and the area desiccated with *glyphosate* herbicide in
142 preparation for the subsequent summer sowing. The average annual fertilization applied
143 during the 14-yr experimental period was 150 kg N ha⁻¹, 30 kg P ha⁻¹ and 50 kg K ha⁻¹,
144 fertilized during the pasture cycle. The season and annual fertilization rates can be found
145 in Alves et al. (2019). The maize was fertilized with rates of 110 and 150 kg N ha⁻¹,
146 respectively, only in 2009/2010 and 2011/2012 growing seasons.

147 In the cropping phase, each plot was divided into two subplots. Each subplot was
148 divided in two crop systems: monoculture - soybean/soybean and crop rotation -
149 soybean/maize (50%-50%), both under no-tillage. In the first summer cycle soybean
150 (*Glycine max*) was sown in the whole experimental area. In the second cycle soybean was

151 sown in half the subplot and maize in the other half (subplots monoculture and crop
152 rotation, respectively), with 45 cm between lines and a population of 280,000 plants ha⁻¹. Soybean and maize were sown from October to November.

154

155 2.2. Crop yield

156 Soybean yield was evaluated over five crop/growing seasons (2003/2004,
157 2004/2005, 2006/2007, 2010/2011 and 2014/2015). The maize yield was evaluated over
158 six crop/growing seasons (2005/2006, 2007/2008, 2009/2010, 2011/2012, 2013/2014 and
159 2015/2016).

160 Yield was evaluated by collecting from five random points in each subplot, each
161 point with two linear meters, totalling 4.5 m². After collection, the samples were dried
162 and the grain yield presented 130 g kg⁻¹ of moisture content.

163

164 2.3. The water requirement satisfaction index (WRSI) of the soybean and maize crops

165 The WRSI was calculated from the ratio between real (E_{Tr}) and maximum
166 evapotranspiration (E_{Tm}) of the crop (soybean or maize). When water requirement and
167 supply meet, the WRSI is equal to 1 (E_{Tr} = E_{Tm}). When the E_{Tr} < E_{Tm}, the crop yield
168 may be limited by deficit water stress. The WRSI was calculated for all years from
169 October 15 to March 15, including the period from sowing to harvesting of the summer
170 crops (soybeans and corn) (Fig. S1). For the correlation study between WRSI and crop
171 yield, the reproductive period (stages R1-R6) was used as this period is critical for a good
172 crop yield (Franchini et al. 2012).

173 The values of E_{Tr} and E_{Tm} were determined for the soybean and maize crop
174 cycle. The BIPZON model was used to simulate the crop hydric balance (Forest, 1984).
175 This model allows the input of data from converging variables such as climate (rainfall

176 and average daily temperature); crop (coefficient of the crop K_c); and soil (available water
177 capacity). The available water capacity was estimated for the first 50 cm of soil,
178 considering an effective root depth of 60 mm.

179

180 *2.4. Determination of forage production*

181 Above-ground productivity (AGP, Mg ha^{-1}) of the pasture was evaluated in the
182 years 2004, 2005, 2006, 2007, 2010, 2011, 2012, 2015 and 2016. The AGP was calculated
183 by using the accumulated forage mass at the beginning of the grazing period, added to the
184 forage accumulation rate (kg day^{-1}) and multiplied by the number of grazing days, over
185 an average period of 101 ± 9 days.

186 The residual aboveground forage mass (RFM, Mg ha^{-1}) was calculated at the end
187 of the grazing period in the years 2010, 2011, 2012, 2015 and 2016, using subsamples.
188 Samples were collected randomly using a 0.25m^2 metal frame (0.5×0.5 m). All the
189 remaining above ground forage, was cut and dried in an oven with air circulation at 65
190 $^{\circ}\text{C}$ for 72 hours. After drying, the material was weighed and the results expressed as Mg
191 ha^{-1} .

192

193 *2.5. Soil sampling and analyses of the C and N content of the soil*

194 The soil was sampled with an auger at the layers 0–5, 5–10, 10–20 and 20–30 cm.
195 The samples were dried in a forced-air oven at 45°C . The larger lumps broken up, ground
196 and sieved with a 2.0 mm sieve. A 2.0 g subsample was ground and sieved to ≤ 0.100 mm.
197 The soil C and N contents were analysed by dry combustion in a Fisher Scientific
198 FlashEA[®]. Bulk density was measured using the volumetric ring method (Blake and
199 Hartge, 1986), in the 0–10, 10–20 and 20–30 cm layers. Then, the C and N stocks in the
200 0–30 cm layer were calculated by the soil mass method (Ellert and Bettany, 1995). The

201 soil used as the reference was sampled from the treatment with moderate grazing intensity
202 under the continuous stocking method and soybean monoculture. The soil density in the
203 0–10 cm layer was used in the calculation of the C and N stocks in the 0–5 and 5–10 cm
204 layers.

205 Soil C accumulation rates were calculated with the ratio between the C stock of the
206 soil and the soil with the lowest C stock (crop rotation, moderate grazing intensity and
207 continuous stocking method) over the duration of the experiment (14-yr).

208

209 2.6. Statistical analyses

210 Statistical analysis was performed with SAS® 9.4 software and the results were
211 subjected to a normality analysis by the Shapiro-Wilk test and the homogeneity of
212 variances by the Levene test, both at a significance level of 5%. The results were
213 submitted to ANOVA at a 5% significance level (ANOVA, $P > 0.05$). When significant,
214 the difference between the treatment means was evaluated by the Tukey test, also at 5%.

215 A factorial model with split plots was used for the analysis of soybean yield and
216 RFM. The effects were two stocking methods and two grazing intensities, with the
217 cropping systems subdivided in plots, considering the effects of the block (B), the
218 stocking method (M), grazing intensity (I), cropping system (S), the interactions M*I,
219 M*S, I*S, M*I*S and the year as a repeated measure of time. A factorial model was used
220 for the analysis of maize yield and AGP, considering the B, M, I effects and the M*I
221 interaction, and the year as a repeated measure of time. The factorial model used
222 subdivided sub-plots for the C and N content in the soil, with the soil layer as the
223 subdivided sub-plot, considering the effects B, M, I, S, soil layer (C) and the interaction
224 between M*I, M*S, I*S, M*I*S, M*C, I*C, S*C, M*I*C, M*S*C, I*S*C and M*I*S*C.
225 For the stocks and the accumulation rates of C and N in the soil, considering the effects

226 B, M, I, S and the interaction between M*I, M*S, I*S and M*I*S. In all models, the B
227 effect and its interactions were considered random effects and the other factors were
228 considered fixed effects.

229 The significance of the **relationship** between C and N content in the soil and C and
230 N inputs by crops and/or pasture was evaluated using Pearson's correlation coefficients
231 (r) at the 5% level.

232

233 **3. Results**

234 *3.1. Crop and forage production*

235 Soybean yield was not affected by the cropping system (**Tables 1 and 2**). In two
236 **(2003/2004 and 2006/2007)** of the five **harvests** evaluated, soybean yield was not affected
237 by stocking **method** and grazing **intensity**. In the 2004/2005 season, the **adoption of**
238 rotational stocking method, **favour greater** soybean yield in continuous-moderate **(30%)**
239 and continuous-low **(272%)** (**Tables 1 and 2**). On the other hand, in the 2010/2011
240 season, lower soybean yield was observed in **the** continuous-moderate treatment
241 compared to the other treatments. In the 2014/2015 season, **independent of the** grazing
242 intensity, the average soybean yield observed in rotational stocking method was 48%
243 greater than continuous stocking method (**Table 2**). The highest soybean yield during the
244 experimental period was observed in the 2014/2015 season, with an average of 3.0 Mg
245 ha⁻¹.

246 **Maize** yield was slightly affected by the stocking methods and grazing intensities.
247 Maize yield was low throughout the evaluation period, ranging from 1.9 Mg ha⁻¹ in the
248 2007/2008 season to 7.7 Mg ha⁻¹ in the 2015/2016 season (**Fig. 1**). Although maize
249 showed a tendency for higher yields at low grazing intensity, this result was significant
250 only in the 2015/2016 season, which also had the highest maize yields compared to other

251 seasons (**Fig. 1**). In the 2015/2016 season, grain yield **in** low grazing intensity was 40%
252 higher (2.4 Mg ha⁻¹) than **in** moderate intensity.

253 **Fig. 2A** presents the relationship between WRSI and maize yield **under** different
254 grazing intensities (moderate and low). At low grazing intensity, for every 0.1 unit
255 increase in WRSI, maize yield increased by 0.97 Mg ha⁻¹, *versus* 0.64 Mg ha⁻¹ at moderate
256 grazing intensity. In **Fig. 2B**, the relationship between WRSI and soybean yield is
257 presented **under combination of** stocking method and grazing intensity: continuous-low,
258 continuous-moderate, rotational-low and rotational-moderate. **Under** continuous stocking
259 method with low grazing intensity, **the increase of 0.1 unit increase in WRSI favoured the**
260 **increased of soybean yield by 0.24 Mg ha⁻¹ versus 0.20 Mg ha⁻¹ under** continuous stocking
261 method **with** moderate grazing intensity. **The relationship was not significant under**
262 rotational stocking method.

263 **AGP** ranged from 4.8 to 16.8 Mg ha⁻¹ and was affected by grazing intensity (**Fig.**
264 **3**). Over the experimental period, **AGP in** low intensity grazing (11.1 Mg ha⁻¹) was 32%
265 higher than in moderate grazing intensity (8.4 Mg ha⁻¹) (**Fig. 3**). RFM **aboveground** was
266 affected by grazing intensity and cropping system over the experimental period (**Table**
267 **1**). RFM mean was 7% higher in soybean monoculture (3.1 Mg ha⁻¹) than in crop rotation
268 (2.8 Mg ha⁻¹) (**Fig. 4**). **Regarding** grazing intensities, low grazing intensity (3.4 Mg ha⁻¹)
269 resulted in 28% more residue than moderate intensity (2.7 Mg ha⁻¹) (**Fig. 4**).

270

271 3.2. Soil C and N content and stocks

272 C and N content in the superficial soil layers (0–5 and 5–10 cm) were affected by
273 cropping systems, as well as grazing intensities (**Table 1 and Fig. 5**). In the 0–10 cm
274 layer, the average C **concentration** under low grazing intensity was 20% higher (14.1 g
275 kg⁻¹) than under moderate grazing intensity (11.8 g kg⁻¹) (**Fig. 5B**). Using the average **of**
276 **the** two layers (0–5 and 5–10 cm), the highest N **concentration** were observed under low

277 grazing intensity (1.5 g kg⁻¹) compared to under moderate grazing intensity (1.2 g kg⁻¹)
278 (Fig. 5D). Greater C and N concentration in 0–5 and 5–10 cm soil layers was observed in
279 soybean monoculture, averaging in the 0–10 cm layer 14.3 and 1.6 g kg⁻¹ of C and N,
280 respectively, which is around 22 and 27% greater than crop rotation system (Fig. 5A and
281 5C).

282 C and N stocks in the 0–30 cm soil layer ranged from 39 to 45 Mg ha⁻¹ and 3.9 to
283 4.9 Mg ha⁻¹, respectively, and were affected by cropping system and grazing intensities.
284 Higher C and N stock in 0–30 cm soil layer was observed in soybean monoculture (45
285 and 5 Mg ha⁻¹, respectively) compared to crop rotation system (39 and 4 Mg ha⁻¹,
286 respectively) (Table 4). This led to significant accumulation rates of 500 kg C ha⁻¹ yr⁻¹
287 and 78 kg N ha⁻¹ yr⁻¹ in the soil under soybean monoculture (Table 4). In addition, C and
288 N stock was 11 and 9% higher, respectively, under low grazing intensity compared to
289 moderate grazing. Soil accumulation rates was 500 kg C ha⁻¹ yr⁻¹ and 57 kg N ha⁻¹ yr⁻¹
290 under low intensity and 200 kg C ha⁻¹ yr⁻¹ and 27 kg N ha⁻¹ yr⁻¹ under moderate grazing
291 intensity (Table 4).

292 Significant relationships between the input of C (Fig. 6A) and N (Fig. 6B) via
293 crop residues from each cropping system, monoculture and crop rotation, and the C stock
294 were observed. Each 1000 kg of C annually inputted via above-ground biomass, the C
295 stock increased by 14.5 kg ha⁻¹ in soybean monoculture, versus 4.5 kg ha⁻¹ in the crop
296 rotation system. For N inputs, each 10 kg of N annually inputted via above-ground
297 biomass, the N stock increased by 0.53 Mg ha⁻¹ in soybean monoculture, versus 0.30 Mg
298 ha⁻¹ in the crop rotation system.

299

300 4. Discussion

301 Our study showed that low grazing intensities favour significant increases in soil
302 C and N stocks in subtropical environments, which corroborate to previous studies (Souza
303 et al., 2009; Assmann et al., 2014). In our study, considering the 0–30 cm soil layer, the
304 highest rates of C and N accumulation were observed in the systems with low intensity
305 grazing and soybean monoculture (Table 4). This higher soil accumulation is associated
306 with higher C and N input via crop residues at low compared to moderate grazing intensity
307 (annual difference 2.7 Mg ha⁻¹), as demonstrated by the higher AGP (Table 3 and Fig.
308 3). This higher C and N input in low grazing intensity is due to lower forage intake by the
309 lower number of sheep, leading consequently to higher AGP and RFM (Fig. 3 and 4).

310 Soybean monoculture promoted greater increase in soil C when compared to crop
311 rotation. Although the relationship between soil C stock and C input was significant in
312 both soybean monoculture and crop rotation systems (Fig. 6A), for each kg of C added
313 annually via plant residues, there was an increase of 14.5 kg C ha⁻¹ under soybean
314 monoculture and 4.5 kg C ha⁻¹ under crop rotation. In addition, N input via residues
315 caused alterations in the soil C stocks under both cultivation systems. Each kg of N added
316 annually via plant residues generated greater increase under soybean monoculture (0.53
317 Mg C ha⁻¹) than under crop rotation (0.30 Mg C ha⁻¹). (Fig. 6B). Thus, our results suggests
318 that residue quality was the main driver for soil C accumulation, as observed by Manzonei
319 et al. (2008), which is possibly associated to greater efficiency of microorganisms in
320 stabilizing C from labile (higher N content) plant residue into microbial residues that later
321 might be stabilized in organo-mineral association (Cotrufo et al., 2013, 2015, Veloso et
322 al., 2019).

323 The effect of higher N supply for forage production in succession, is probably due
324 to the high biological N fixation which is used to supply the needs of the soybean crop,
325 therefore reducing the dependence on N from mineralization of the SOM (Ciampitti and

326 Salvagiotti, 2018). The higher N supply available for the subsequent pasture cultivation
327 in soybean monoculture system is associated to both lower C/N ratio and higher N input
328 through crop residues to the soil, favouring then higher RFM compared to maize. Varvel
329 and Wilhelm (2003) also observed that the soybean crop could contribute larger quantities
330 of N to subsequent crops, giving better conditions for the development of pasture in
331 contrast to maize. In addition, the absence of N fertilization under maize (except for the
332 2009/2010 and 2011/2012 seasons), probably contributed to high N immobilization,
333 negatively affecting the initial development of the successive hibernal pasture (Campos,
334 2015) when compared to soybean monoculture system.

335 Mainly due to the frequent droughts (as indicated by the low WRSI observed
336 during the majority of the crop seasons - Fig. 2), the average C input over the experimental
337 period was 2.4 Mg ha⁻¹ in the crop rotation system (Table 3), very similar to that observed
338 in the soybean monoculture. Although maize adoption in cropping systems in subtropical
339 environments is a viable alternative with a potential for a C input higher than 4 Mg ha⁻¹
340 (Veloso et al, 2018), the C input by maize in this study was much lower than expected.

341 The greater maize grain yield after low intensity grazing in 2015/2016 season
342 (Fig. 1) is possibly related to the higher C and N soil content in this system obtained in
343 the long-term compared to moderate intensity grazing (Table 4). It can also be explained
344 by the higher WRSI, which showed a linear relationship with yield (Fig. 2). Thus, the
345 system using low grazing intensity, which had a higher capacity to supply the nutritional
346 needs, especially N due to the larger soil stock, was more favoured under superior water
347 supply conditions. (Fig. 2).

348 The soybean grain yield did not respond positively to increases in soil N levels
349 caused by the adoption of low grazing intensities. (Table 2). This is mainly due to the
350 fact that the treatments in this study do not affect other chemical attributes of the soil

351 (Alves et al, 2019) and because soybeans obtain much of their N requirement from
352 biological N fixation, depending less of N soil supply (Ciampitti and Salvagiotti, 2018)
353 in contrast to maize. However, soybean yield was affected by the different pasture
354 management methods and grazing intensities (Table 2). The rotational method,
355 independent of the grazing intensity, resulted in higher soybean yield when compared to
356 the continuous method adopted in the 2004/2005 and 2014/2015 seasons (Table 2). The
357 higher soybean yield in the rotational stocking method can be justified by the fact that
358 continuous grazing can affect spatial patterns of the soil attributes, increasing spatial
359 heterogeneity of the pastures and the environment (Laca, 2009, Auerwald et al., 2010).
360 As the animals circulate freely selecting grazing areas, manure is deposited unevenly
361 influencing the concentration of nutrients in the soil (McNaughton, 1985; Augustine &
362 Frank, 2001), with the highest concentrations being found near to the rest areas, shade
363 and water troughs (Dennis et al. 2012; Dubeux et al., 2014). This does not happen using
364 the rotational stocking method, where the animals are placed in grazing ranges that rotate
365 in space and time, favouring the better distribution of manure within the grazing range
366 (Peterson and Gerrish, 1996), achieving better control of spatial nutrient cycling and soil
367 fertility.

368

369 5. Conclusions

370 The aboveground productivity of pasture and the maize yield are higher in the
371 system with low grazing intensity during the pasture phase. In contrast, soybean presented
372 higher yield when the rotational pasture method was used in the winter, regardless of the
373 grazing intensity. The residual forage mass in the pasture phase was favoured by the
374 soybean monoculture system in the summer.

375 Low grazing intensity in the pasture phase favoured the increase in the C and N
376 stocks in the soil. The pasture management method, continuous or rotational, did not
377 affect the accumulation of C and N in the soil. The higher quality of soybean crop residues
378 and similar annual input of C determined higher soil C and N stocks, in comparison to
379 the rotation soybean/maize. Thus, our results provided field-based evidence that crop
380 residues with greater N content, favoured soil C accumulation. Maize yield was low in
381 most of the seasons due to the low water requirement satisfaction index, reducing the
382 potential for the accumulation of C and N in the soil under rotation soybean/maize.

- 384 Assmann, J. M., Anghinoni, I., Martins, A. P., de Andrade, S. E. V. G., Cecagno, D.,
385 Carlos, F. S., Carvalho, P. C. F., 2014. Soil carbon and nitrogen stocks and fractions in a
386 long-term integrated crop–livestock system under no-tillage in southern Brazil. *Agr.*
387 *Ecosyst. Environ.* 190, 52-59. <https://doi.org/10.1016/j.agee.2013.12.003>
- 388 Auerswald, K., Mayer, F., Schnyder, H., 2010. Coupling of spatial and temporal pattern
389 of cattle excreta patches on a low intensity pasture. *Nutr. Cycl. Agroecosys.* 88, 275-288.
390 <https://10.1007/s10705-009-9321-4>
- 391 Augustine, D. J., Frank, D. A., 2001. Effects of migratory grazers on spatial heterogeneity
392 of soil nitrogen properties in a grassland ecosystem. *Ecology* 82, 3149-3162.
393 <https://10.2307/2679841>
- 394 Barthram, G.T., 1985. Experimental Techniques: The HFRO Sward Stick. The Hill
395 Farming Research Organization/Biennial Report. HFRO, Penicuik, pp. 29-30.
- 396 Bayer, C., Lovato, T., Dieckow, J., Zanatta, J. A., Mielniczuk, J., 2006. A method for
397 estimating coefficients of soil organic matter dynamics based on long-term
398 experiments. *Soil Till. Res.* 91(1-2), 217-226. <https://doi.org/10.1016/j.still.2005.12.006>
- 399 Blake, G.R., Hartge, K.H., 1986. Bulk density. In: Klute, A. (Ed.), *Methods of Soil*
400 *Analysis, Part 1. Physical and Mineralogical Methods.* ASA/SSSA, Madison, pp. 363-
401 382. <https://doi:10.2136/sssabookser5.1.2ed.frontmatter>
- 402 Campos, B. M., 2015. Estabelecimento do azevém anual em sistemas integrados de
403 produção agropecuária: implicações do resíduo das lavouras de soja e milho. 48 f.
404 Dissertação (Mestrado) - Pós-Graduação em Agronomia – Produção Vegetal.
405 Universidade Federal do Paraná, Curitiba - PR.
- 406 Carvalho, J. L. N., Raucci, G. S., Frazão, L. A., Cerri, C. E. P., Bernoux, M., Cerri, C. C.,
407 2014. Crop-pasture rotation: A strategy to reduce soil greenhouse gas emissions in the
408 Brazilian Cerrado. *Agr. Ecosyst. Environ.* 183, 167–175.
409 <https://doi:10.1016/j.agee.2013.11.014>
- 410 Carvalho, P. C. F., Anghinoni, I., Moraes, A., Souza, E. D., Sulc, R. M., Lang, C. R.,
411 Flores, J. P. C, Lopes, M. L. R., Silva, J. L. S., Conte, O., Wesp, C. L., Levien, R.,
412 Fontaneli, R. S., Cimelio Bayer, C., 2010. Managing grazing animals to achieve nutrient
413 cycling and soil improvement in no-till integrated systems. *Nutr. Cycl.*
414 *Agroecosys.* 88(2), 259-273. <https://doi.org/10.1007/s10705-010-9360-x>
- 415 CFS-RS/SC – Comissão de Fertilidade Do Solo - RS/SC, 1995. Recomendações de
416 adubação e de calagem para os Estados do Rio Grande do Sul e de Santa Catarina, 3 ed.
417 SBCS - Núcleo Regional Sul/EMBRAPA-CNPT, Passo Fundo, 224 p.
- 418 Chen, J., Heiling, M., Resch, C., Mbaye, M., Gruber, R., Dercon, G., 2018. Does maize
419 and legume crop residue mulch matter in soil organic carbon sequestration? *Agr. Ecosyst.*
420 *Environ.* 265, 123-131. <https://doi.org/10.1016/j.agee.2018.06.005>
- 421 Ciampitti, I. A., Salvagiotti, F., 2018. New Insights into Soybean Biological Nitrogen
422 Fixation. *Agron. J.* 110(4), 1185. <https://10.2134/agronj2017.06.0348>

- 423 CONAB, 2019. Observatório Agrícola: Acompanhamento da Safra Brasileira de Grãos,
424 6 (6) - safra 2018/19. URL.
425 [https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc](https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc6c0c7f53522a)
426 [6c0c7f53522a](https://www.conab.gov.br/component/k2/item/download/25183_cb54effd57f6232cedcc6c0c7f53522a) (accessed 14 June 2019).
- 427 Cotrufo, M. F., Wallenstein, M. D., Boot, C. M., Deneff, K., Paul, E., 2013. The Microbial
428 Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition
429 with soil organic matter stabilization: do labile plant inputs form stable soil organic
430 matter? *Glob. Change Biol.* 19(4), 988-995. <https://doi.org/10.1111/gcb.12113>
- 431 Cotrufo, M. F., Soong, J. L., Horton, A. J., Campbell, E. E., Haddix, M. L., Wall, D. H.,
432 Parton, W. J., 2015. Formation of soil organic matter via biochemical and physical
433 pathways of litter mass loss. *Nat. Geosci.* 8(10), 776-781. <https://10.1038/NNGEO2520>
- 434 CQFS-RS/SC – Comissão De Química E Fertilidade Do Solo - RS/SC, 2004. Manual de
435 adubação e calagem para os Estados do Rio Grande do Sul e Santa Catarina. Porto Alegre:
436 SBRS - Núcleo Regional Sul/EMBRAPA-CNPT, 400 p.
- 437 Dennis, S.J., Moir, L. J., Cameron, K. C., Edwards, G. R., Di, H. J., 2012. Measuring
438 excreta patch distribution in grazed pasture through low-cost image analysis. *Grass*
439 *Forage Sci.* 68:378–385. <https://10.1111/gfs.12000>
- 440 Dubeux, J. C. B., Sollenberger, L. E., Vendramini, J. M. B., Interrante, S. M., Lira, M.
441 A., 2014. Stocking Method, Animal Behavior, and Soil Nutrient Redistribution: How are
442 They Linked? *Crop Sci.* 54(5), 2341-2350. <https://10.2135/cropsci2014.01.0076>
- 443 Ellert, B. H., Bettany, J. R., 1995. Calculation of organic matter and nutrients stored in
444 soils under contrasting management regimes. *Can. J. Soil Sci.* 75(4), 529-538.
445 <https://doi.org/10.4141/cjss95-075>
- 446 FAO, I, 2006. World reference base for soil resources 2006. In: World Soil Resources
447 Reports No. 103. FAO, Rome.
- 448 Forest, F., 1984. Simulation du bilan hydrique des cultures pluviales. In: Présentation et
449 utilisation du logiciel BIP, Irat-Cirad, Montpellier, p. 63.
- 450 Franchini, J. C., Debiase, H., Junior, A. A. B., Tonon, B. C., Farias, J. R. B., de Oliveira,
451 M. C. N., Torres, E., 2012. Evolution of crop yields in different tillage and cropping
452 systems over two decades in southern Brazil. *Field Crop. Res.* 137, 178-185.
453 <https://doi.org/10.1016/j.fcr.2012.09.003>
- 454 Ghosh, S., Wilson, B. R., Mandal, B., Ghoshal, S. K., Grown, I., 2010. Changes in soil
455 organic carbon pool in three long-term fertility experiments with different cropping
456 systems and inorganic and organic soil amendments in the eastern cereal belt of
457 India. *Soil Res.* 48(5), 413-420. <https://doi.org/10.1071/SR09089>
- 458 Laca, E. A., 2009. New Approaches and Tools for Grazing Management. *Rangeland Ecol.*
459 *Mana.* 62(5), 407-417. <http://doi.org/10.2111/08-104.1>.
- 460 Lal, R., 2004. Soil carbon sequestration impacts on global climate change and food
461 security. *Science.* 304(5677), 1623-1627. <https://10.1126/science.1097396>
- 462 Luz, F. B., Silva, V. R., Mallmann, F. J. K., Pires, C. A. B., Debiase, H., Franchini, J. C.,
463 Cherubin, M. R., 2019. Monitoring soil quality changes in diversified agricultural

464 cropping systems by the Soil Management Assessment Framework (SMAF) in southern
465 Brazil. *Agr. Ecosyst. Environ* 281, 100-110. <https://doi.org/10.1016/j.agee.2019.05.006>

466 Manzoni, S., Jackson, R. B., Trofymow, J. A., Porporato, A., 2008. The global
467 stoichiometry of litter nitrogen mineralization. *Science*. 321(5889), 684-686.
468 <https://10.1126/science.1159792>

469 McNaughton S. J.; 1985. Ecology of grazing ecosystem: the Serengeti. *Ecol. Monogr.* 55,
470 259-295. <http://dx.doi.org/10.2307/1942578>.

471 Moraes, A., Carvalho, P.C.F., Anghinoni, I., Lustosa, S.B.C., Costa, S.E.V.G.A.,
472 Kunrath, T.R., 2014. Integrated crop-livestock systems in the Brazilian subtropics. *Eur.*
473 *J. Agron.* 57 (4–9), 2014. <https://doi.org/10.1016/j.eja.2013.10.004>

474 Mott, G.O., Lucas, H.L., 1952. The design conduct and interpretation of grazing trials
475 on cultivated and improved pastures. In: *International Grassland Congress*, 6, 1952,
476 Pennsylvania. Proceeding. State College, Pennsylvania, pp. 1380–1395.

477 National Research Council, 1985. *Nutrient Requirement of Sheep*, 6th ed. National
478 Academy of Science, Washington (99p).

479 Reeder, J. D., Schuman, G. E., 2002. Influence of livestock grazing on C sequestration in
480 semi-arid mixed-grass and short-grass rangelands. *Environ. Pollut.* 116(3), 457-463.
481 [https://doi.org/10.1016/S0269-7491\(01\)00223-8](https://doi.org/10.1016/S0269-7491(01)00223-8)

482 Peterson, P.R., and J.R. Gerrish., 1996. Grazing systems and spatial distribution of
483 nutrients in pastures: Livestock management considerations. In: C.A. Roberts, editor,
484 *Nutrient cycling in forage systems*. 203–212.

485 Russelle, M. P., Birr, A. S., 2004. Large-scale assessment of symbiotic dinitrogen fixation
486 by crops. *Agron. J.* 96(6), 1754-1760. <https://10.2134/agronj2004.1754>

487 Sá, J. C. M, Lal, R., Cerri, C. C., Lorenz, K., Hungria, M., Carvalho, P. C. F., 2017. Low-
488 carbon agriculture in South America to mitigate global climate change and advance food
489 security. *Environ. Int.* 98, 102-112. <https://doi.org/10.1016/j.envint.2016.10.020>

490 Soussana, J.F., Lemaire G., 2014. Coupling carbon and nitrogen cycles for
491 environmentally sustainable intensification of grasslands and crop-livestock systems.
492 *Agric. Ecosyst. Environ.* 190, 9-17. <https://doi.org/10.1016/j.agee.2013.10.012>

493 Souza, E. D. D., Costa, S. E. V. G. D. A., Anghinoni, I., Carvalho, P. C. D. F., Andrighetti,
494 M. H., Cao, E. G., 2009. Estoques de carbono orgânico e de nitrogênio no solo em sistema
495 de integração lavoura-pecuária em plantio direto, submetido a intensidades de
496 pastejo. *Rev. Bras. Cienc. Solo.* 33(6), 1829-1836. <https://dx.doi.org/10.1590/S0100-06832009000600031>

498 Varvel, G. E., Wilhelm, W. W., 2003. Soybean Nitrogen Contribution to Corn and
499 Sorghum in Western Corn Belt Rotations. *Agron. J.* 95, 1220-1225.
500 <https://10.2134/agronj2003.1220>

501 Veloso, M. G., Cecagno, D., Bayer, C., 2019. Legume cover crops under no-tillage favor
502 organomineral association in microaggregates and soil C accumulation. *Soil Till.*
503 *Res.* 190, 139-146. <https://doi.org/10.1016/j.still.2019.03.003>

504 Veloso, M.G., Angers, D.A., Tiecher, T., Giacomini, S., Dieckow, J., Bayer, C., 2018.
505 High carbon storage in a previously degraded subtropical soil under no-tillage with
506 legume cover crops. *Agr. Ecosyst. Environ.* 268, 15-23.
507 <https://dx.doi.org/10.1016/j.agee.2018.08.024>

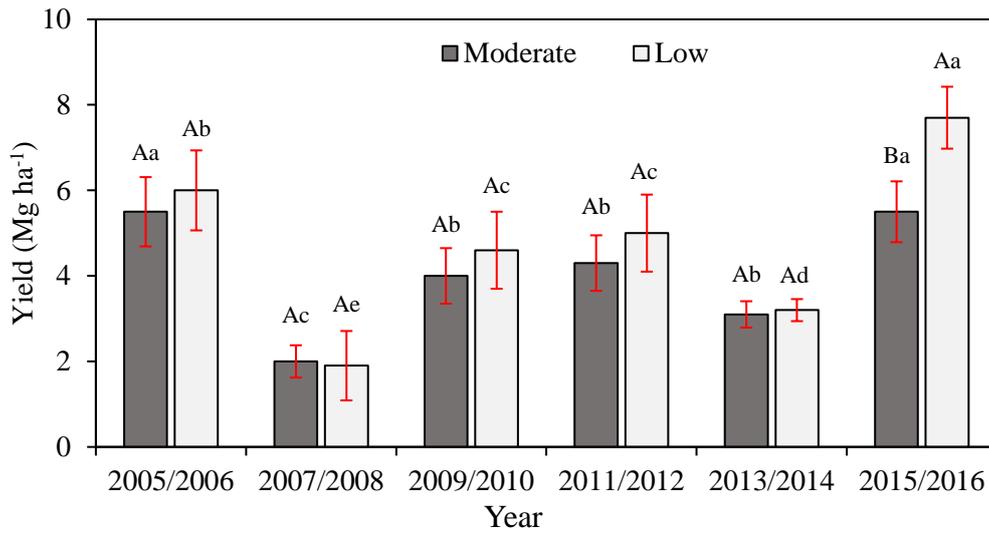


Fig. 1. Grain yield of maize in an integrated crop-livestock system, submitted different grazing intensities (moderate and low) as mean of the stocking methods, in six years (2005, 2007, 2009, 2011, 2013 and 2015), in Southern Brazil. Different letters distinguish maize yield at each grazing intensity in each year (upper case letters) and each grazing intensity in the different years (lowercase letters) by the Tukey test ($p < 0.05$).

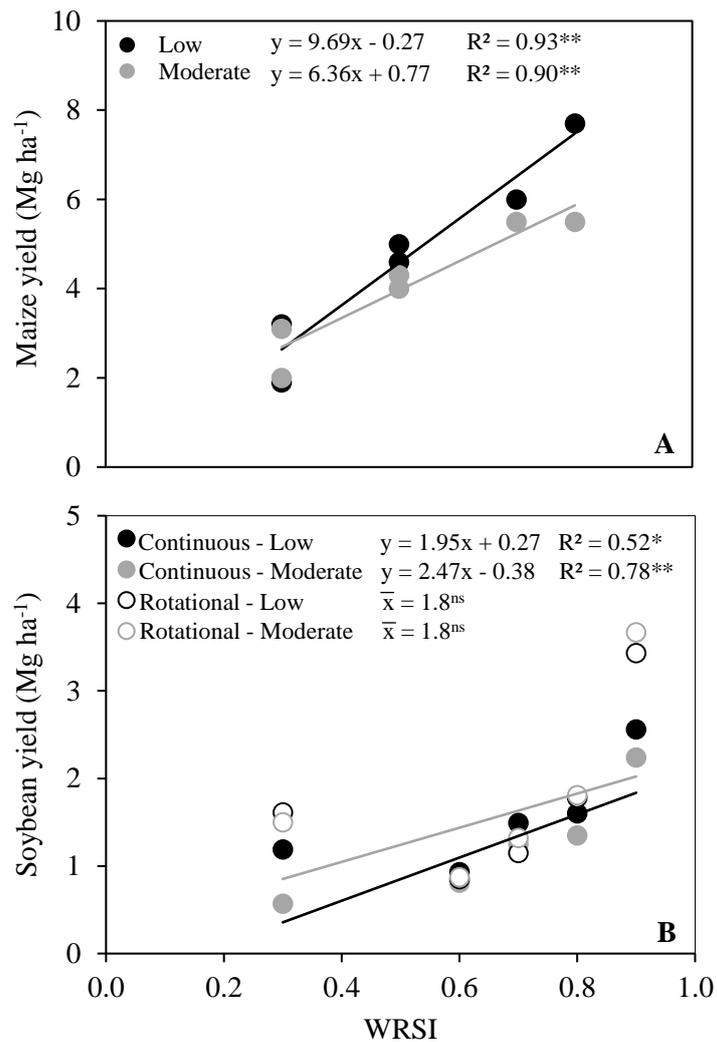


Fig. 2. Relationship between maize yield (**A**) and water requirement satisfaction index (WRSI) to different grazing intensities (moderate and low) and soybean yield (**B**) and WRSI to interaction between stocking methods (continuous and rotational) and grazing intensities (moderate and low) in 14-yr long-term integrated crop-livestock system experiment in Southern Brazil. ****** Significant at $P < 0.01$. ***** Significant at $P < 0.05$. **ns** Not significant.

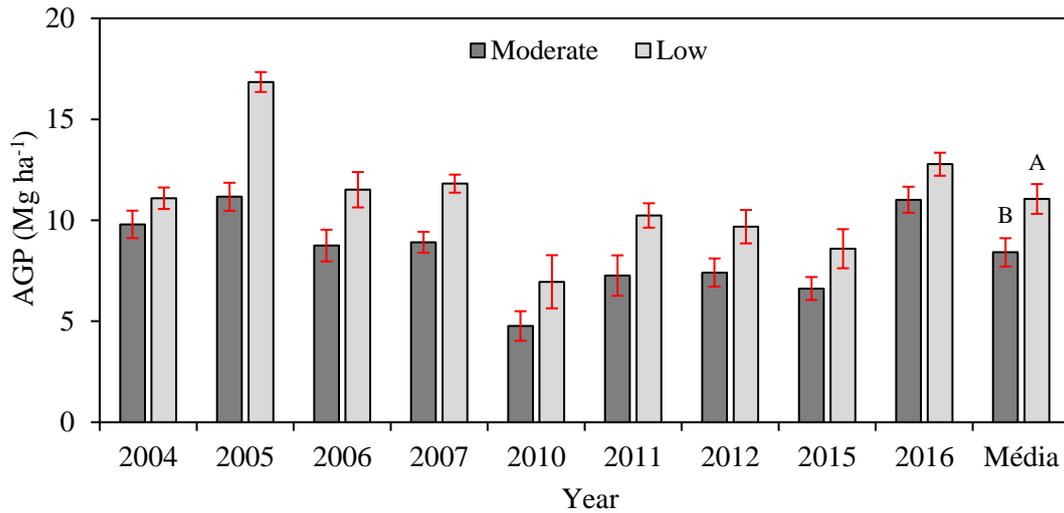


Fig. 3. Aboveground productivity (AGP) (winter ryegrass) in an integrated crop-livestock system under two grazing intensities (moderate and low), **as mean** of the stocking methods in Southern Brazil. Different letters compared the mean of the evaluated years according to the grazing intensities by Tukey test ($p < 0.05$).

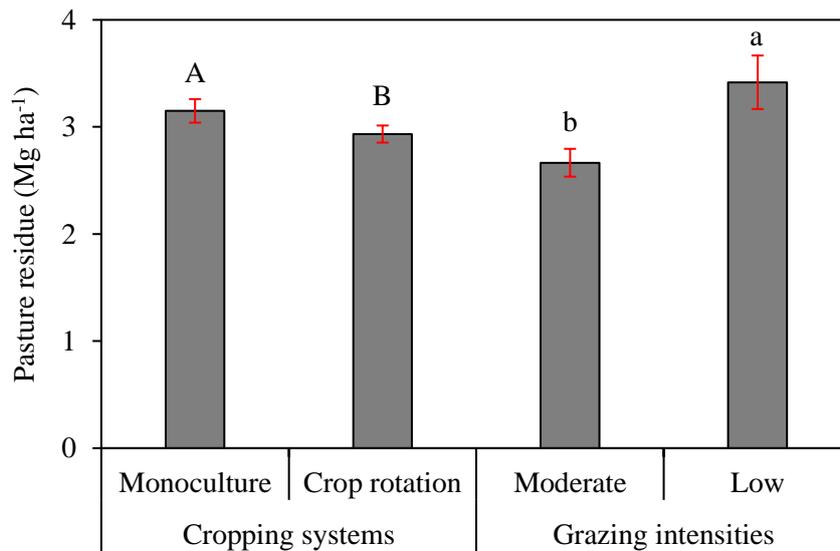


Fig. 4. Residual **aboveground** forage mass (RPM) (winter ryegrass) in an integrated crop-livestock system **under** different cropping systems (soybean monoculture and soybean-maize rotation and grazing intensities (moderate and low) for five years in Southern Brazil. Different letters distinguish RPM in the soil within each cropping **system** (Upper case letters) and grazing **intensity** (Lower case letters) by Tukey test ($p < 0.05$).

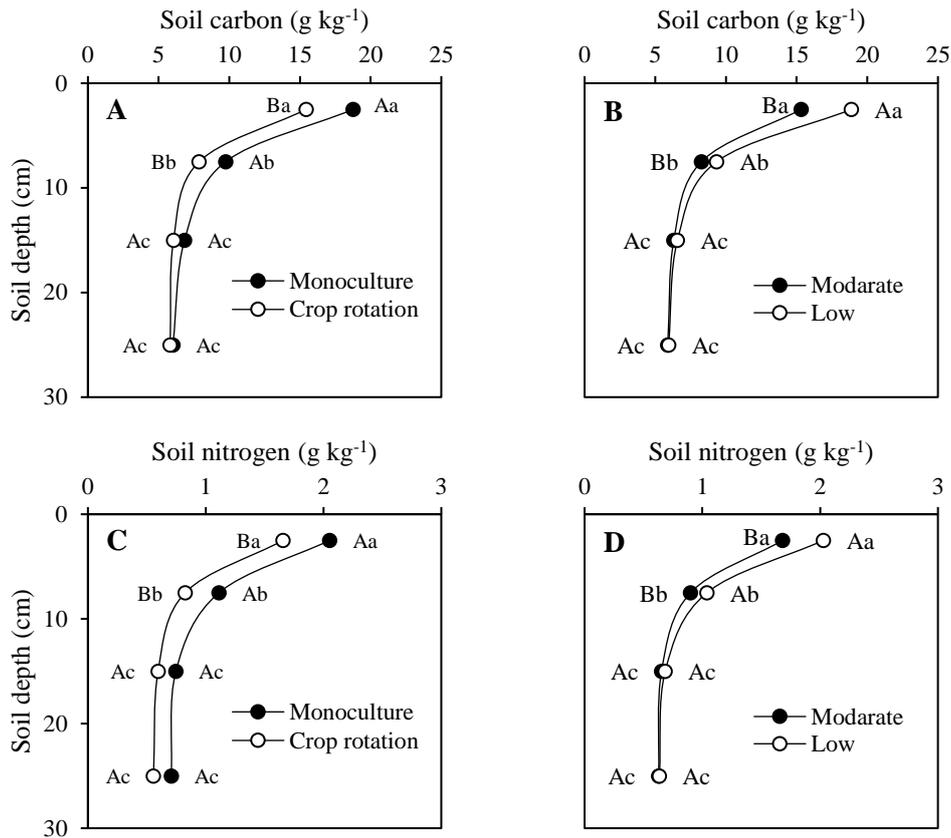


Fig. 5. Soil carbon (**A and B**) and nitrogen (**C and D**) in integrated crop-livestock system under different cropping systems (soybean monoculture and soybean-maize rotation and grazing intensities (moderate and low). When interaction was identified, upper case letters compare the organic carbon contents between the cropping systems within each depth. Lower case letters compare organic carbon contents between depths for each cropping system by Tukey test ($p < 0.05$).

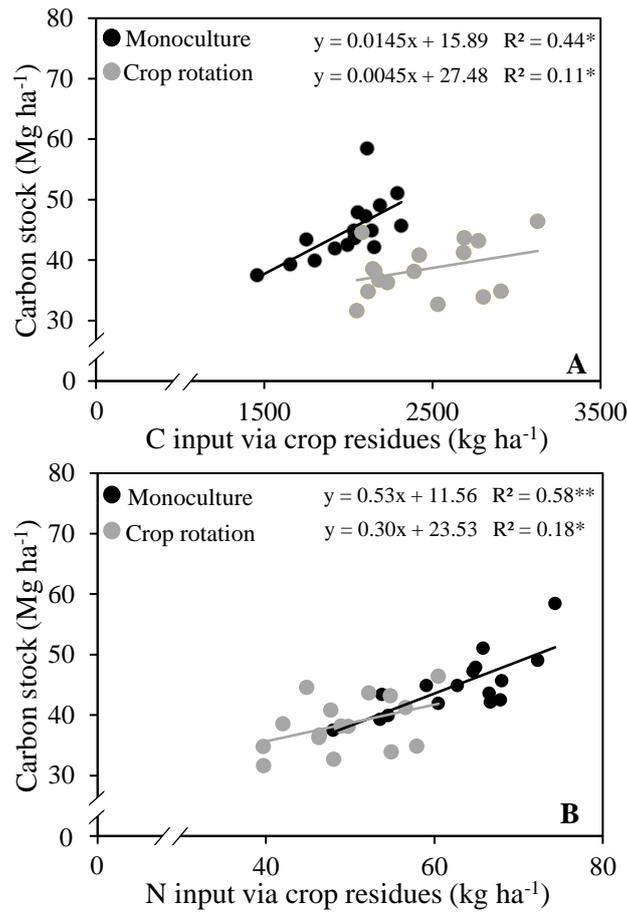


Figure 6. Relationship between carbon (A) and nitrogen (B) inputs via crop residues and soil carbon stocks (0–30 cm) in different cropping systems (monoculture and crop rotation) after 14-yr long-term integrated crop-livestock system experiment in Southern Brazil. ** Significant at $P < 0.01$. * Significant at $P < 0.05$.

Table 1

Analysis of variance of the stocking methods (S), grazing intensity (G), summer cropping systems (C), years (Y), layer (L) and their effect on crop and forage parameters on [soybean and maize grain yield, net primary production (NPP) and residual forage mass (RFM) of winter pasture] over the years and on soil parameters [content C and N in soil, stock of C and N in soil, and annual C and N accumulation rate (C and N-rate) in an Acrisol subjected for 14 years to different winter pasture methods and intensities and summer cropping systems in a long-term integrated crop-livestock protocol in southern Brazil.

Effect	Crop and forage parameters				Effect	Soil parameters					
	Soybean	Maize	NPP	RFM		C content	N content	C stock	N stock	C-rate	N-rate
S	**	ns	ns	ns	S	ns	ns	ns	ns	ns	ns
G	***	*	**	**	G	**	*	**	ns	**	**
C	ns	-	-	*	C	*	**	*	**	**	**
Y	***	***	***	***	L	***	***	-	-	-	-
S × G	**	ns	ns	ns	S × G	ns	ns	ns	ns	ns	ns
S × C	ns	-	-	ns	S × C	ns	ns	ns	ns	ns	ns
S × Y	***	ns	ns	ns	S × L	ns	ns	-	-	-	-
G × C	ns	-	-	ns	G × C	ns	ns	ns	ns	ns	ns
G × Y	ns	***	ns	ns	G × L	**	*	-	-	-	-
C × Y	ns	-	-	ns	C × L	**	*	-	-	-	-
S × G × C	ns	-	-	ns	S × G × C	ns	ns	ns	ns	ns	ns
S × G × Y	**	ns	ns	ns	S × G × L	ns	ns	-	-	-	-
S × C × Y	ns	-	-	ns	S × C × L	ns	ns	-	-	-	-
G × C × Y	ns	-	-	ns	G × C × L	ns	ns	-	-	-	-
S × G × C × Y	ns	-	-	ns	S × G × C × L	ns	ns	-	-	-	-

* Significant at P <0.05; ** Significant at P <0.01; *** Significant at P <0.001; ns not significant.

Table 2

Soybean grain yield in an integrated crop-livestock system **under** different stocking methods (continuous and rotational) and grazing intensities (moderate and low) in five years in southern Brazil.

Year	Continuous		Rotational	
	Moderate	Low	Moderate	Low
	Yield (Mg ha ⁻¹)			
2003/2004	1.25 Ab	1.49 Ab	1.32 Ac	1.15 Ac
2004/2005	0.57 Cc	1.19 Bc	1.50 Ac	1.61 Ab
2006/2007	0.81 Ac	0.93 Ac	0.87 Ad	0.85 Ad
2010/2011	1.35 Bb	1.60 ABb	1.81 Ab	1.78 Ab
2014/2015	2.24 Ba	2.56 Ba	3.67 Aa	3.43 Aa

Upper case letters compare treatments (continuous - moderate, continuous - low, rotational - moderate and rotational - low) in different years. Lower case letters compare the years within each stocking method and grazing intensity. Different by Tukey test $p < 0.05$.

Table 3

Average of annual C and N input to the soil by shoot crop residues of winter ryegrass and summer crops in an integrated crop-livestock system, **under** different grazing intensities (moderate and low) in winter and cropping systems (soybean monoculture and soybean/maize rotation) in summer in Southern Brazil.

Input	Cropping systems		Grazing intensity	
	Monoculture ^a	Crop rotation ^b	Moderate	Low
	Winter (livestock season) contribution (kg ha ⁻¹ year ⁻¹)			
C	1260	1168	1066	1364
N	19	18	16	21
	Summer (crop season) contribution (kg ha ⁻¹ year ⁻¹)			
C	740	1281	955	1073
N	43	31	35	39
Annual input				
C	2000	2449	2020	2437
N	62	49	51	60

^a Soybean residue and ^b Soybean+maize residue in summer; ryegrass residue in winter in both cropping systems.

Table 4

Soil C and N stocks (0–30 cm) in an integrated crop-livestock systems with two grazing intensities (moderate and low) on winter ryegrass and two cropping systems (monoculture and crop rotation) in summer in an Acrisol in Southern Brazil.

Soil parameter	Cropping system		Grazing intensity	
	Monoculture	Crop rotation	Moderate	Low
Stocks ^a (Mg ha⁻¹)				
C	45 A	39 B	40 b	44 a
N	5 A	4 B	4 a	5 a
Annual accumulation rates ^b (kg ha⁻¹)				
C	500 A	200 B	200 b	500 a
N	78 A	6 B	27 b	57 a

^a Different letters distinguish carbon and nitrogen stocks in the soil within each cropping systems (Upper case letters) and grazing intensities (Lower case letters) by Tukey test ($p < 0.05$).

^b The soil C and N accumulation rates were calculated as the difference between C stock in each treatment in relation to the treatment with lower stock (soybean / maize succession, grazing intensity moderate and stocking method continuous), divided by time of the experiment (14 years). Upper case letters compare means of cropping systems, and lower case letters compare means of grazing intensities by Tukey test $p < 0.05$.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

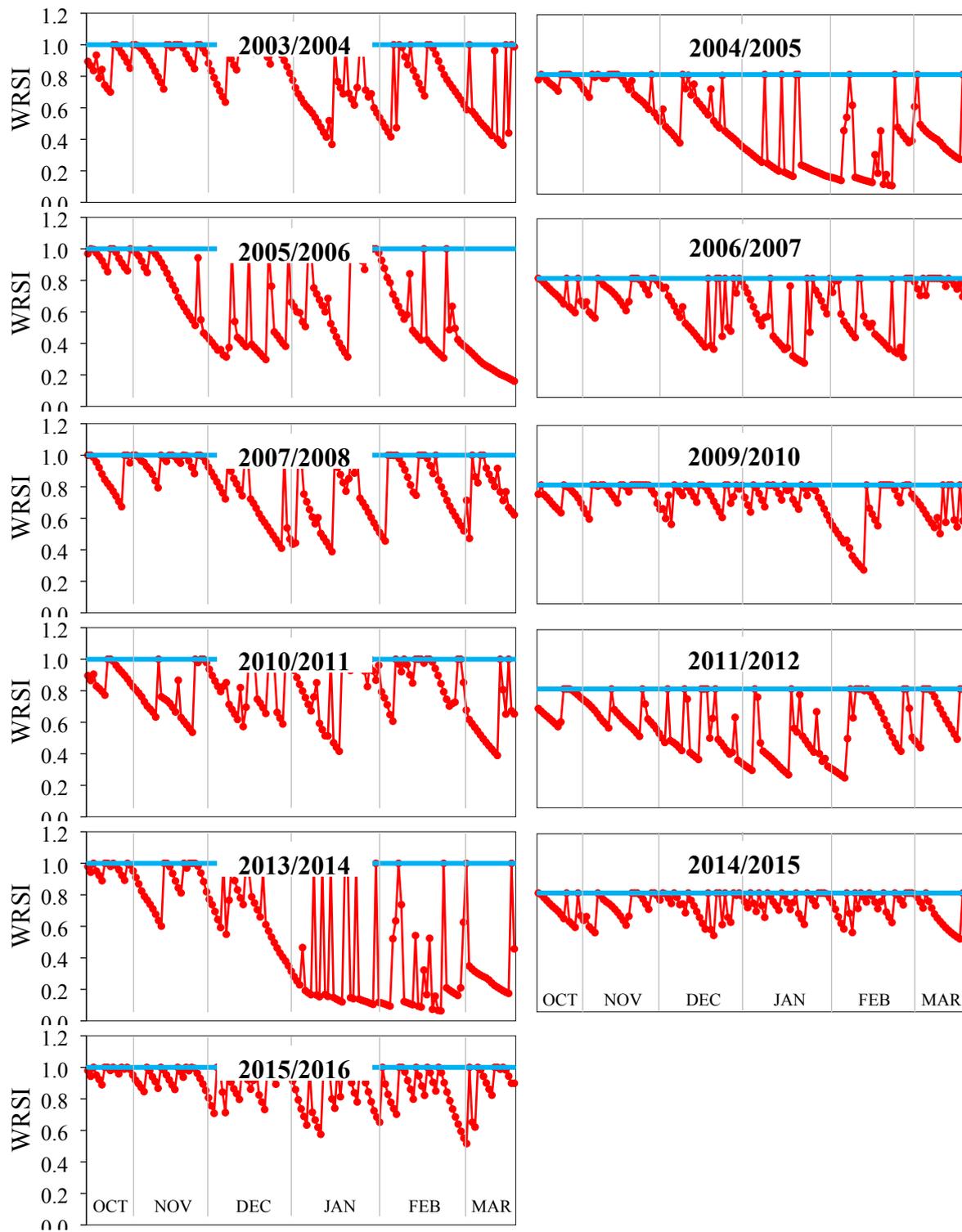
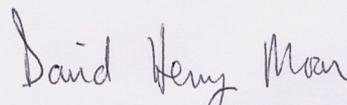


Figure S1. Water requirement satisfaction index (WRSI) for all evaluated harvests in the period from October 15 to March 15.

DECLARATION

I, DAVID HENRY MOON (RNE: V113471-I), revised the main body of the text from the article entitled **“The effect of crop rotation and sheep grazing management on plant production and soil C and N stocks in a long-term integrated crop-livestock system in Southern Brazil”** for the authors Lucas Aquino Alves, Luiz Gustavo de Oliveira Denardin, Amanda Posselt Martins, Cimélio Bayer, Murilo Gomes Veloso Carolina Bremm, Paulo César de Faccio Carvalho, Debora Rubin Machado and Tales Tiecher. I am a British citizen and my mother language is English, received by Degree in Applied Biology from John Moore’s University, Liverpool, UK and my PhD in Virology from the University of Reading, UK.


David Henry Moon

UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

COMISSÃO DE ÉTICA NO USO DE ANIMAIS

Formulário de Encaminhamento de Projeto de Pesquisa à CEUA

ANTES DE PREENCHER ESSE FORMULÁRIO:

1. Certifique-se de que o seu projeto está registrado no Sistema de Pesquisa da UFRGS e contém todas as informações necessárias para avaliação dos aspectos éticos de experimentação animal, conforme as orientações para encaminhamento de projetos apresentadas na página da CEUA/UFRGS.
2. Leia o Guia de Severidade de Procedimentos Científicos na página da CEUA/UFRGS.

A aprovação da CEUA/UFRGS tem validade especificada somente para a atividade na forma em que foi submetida. Mudanças substanciais nas atividades devem ser comunicadas previamente, mediante ofício a CEUA/UFRGS. Exemplos: mudança de número e/ou espécie animal, tratamento, categoria de anestésico usado, método de eutanásia, mudança na substância utilizada e/ou testada, processo invasivo, mudança de severidade do procedimento.

Este documento é um comprovante de que a solicitação deu entrada na CEUA/UFRGS.

1. DADOS DO PROJETO:

Nº do projeto no Sistema de Pesquisa:

Título: Adubação sistêmica como alternativa para intensificação sustentável de sistemas integrados de produção agropecuária

Classificação de severidade de procedimentos: Leve

Departamento ou Programa de Pós-Graduação: Programa de Pós Graduação em Zootecnia

Unidade: Faculdade de Agronomia, UFRGS

Projeto de Tese ou Dissertação? Sim Não

2. PESQUISADOR:

Nome do pesquisador responsável: Carolina Bremm

Cartão UFRGS: 00163042

Unidade: Faculdade de Agronomia, UFRGS.

Telefone para contato: (51) 981176367

E-mail: carolina.bremm@yahoo.com.br

3. COLABORADORES:

Nome completo e vínculo institucional de todos os componentes da equipe:

- Paulo Cesar de Faccio Carvalho – Zootecnista, Dr., Professor Titular do Departamento de Plantas Forrageiras e Agrometeorologia, Faculdade de Agronomia, UFRGS. Pesquisador 1A do CNPq.
- Tales Tiecher – Engenheiro Agrônomo, Dr., Professor Adjunto de Química do Solo do Departamento de Ciência do Solo da Faculdade de Agronomia da UFRGS.
- Amanda Posselt Martins - Eng. Agr., Dr^a., aluna de pós-doutorado do Programa de Pós-Graduação em Ciência do Solo, Faculdade de Agronomia/UFRGS.
- Jean Victor Savian – Zoot., Dr., aluno de pós-doutorado do Programa de Pós-Graduação em Zootecnia, Faculdade de Agronomia/UFRGS.
- Gustavo Duarte Farias – Zoot. M. Sc., aluno de doutorado do Programa de Pós-Graduação em Zootecnia, Faculdade de Agronomia/UFRGS.
- Luis Gustavo Denardin – Eng. Agr., M. Sc., aluno de doutorado do Programa de Pós-Graduação em Ciência do Solo, Faculdade de Agronomia.
- Lucas Aquino Alves – Eng. Agr., aluno de mestrado do Programa de Pós-Graduação em Ciência do Solo, Faculdade de Agronomia/UFRGS.
- Dionata Filippi – Aluno de graduação em Agronomia, bolsista de iniciação científica no Laboratório de química e fertilidade do solo (LQFS), Faculdade de Agronomia da UFRGS.
- Lóren Pacheco Duarte. Aluna de graduação em Zootecnia, Faculdade de Agronomia da UFRGS.
- Luciano Pinzon Brauwerters – Aluno de graduação em Agronomia, bolsista de iniciação científica no Laboratório de química e fertilidade do solo (LQFS), Faculdade de Agronomia da UFRGS.
- Mateus Westerhofer Goulart – Aluno de graduação em Agronomia, bolsista de iniciação científica no Laboratório de química e fertilidade do solo (LQFS), Faculdade de Agronomia da UFRGS.
- Adão Luis Ramos Dos Santos - Departamento de Solos/UFRGS

4. LOCAL:

Nome e endereço do estabelecimento, laboratório ou do biotério onde serão realizados os procedimentos: Estação Experimental da Universidade Federal do Rio Grande do Sul, Eldorado do Sul – RS, Rodovia BR 290, km 146.

5. TEMPO DE EXECUÇÃO:

Período previsto para desenvolver este projeto:

Início (mês/ano): 05/2018

Término (mês/ano): 05/2021

6. TERMO DE RESPONSABILIDADE

Estou ciente dos princípios éticos para o uso de animais para fins didáticos e de pesquisa científica. Conheço e cumprirei a legislação vigente, que normatiza as formas de conduta e tratamento com os animais (Lei 11.794/08 e Decreto 6899/09 da Presidência da República).

Nesse trabalho considerou-se a possibilidade de utilizar métodos alternativos aos modelos animais. Entretanto, concluiu-se que eles não estão disponíveis ou são inadequados por razões científicas. Considerou-se o princípio dos 3R (*replacement, reduction e refinement*, isto é, substituição, redução e refinamento). Ou seja:

- buscou-se a substituição de vertebrados por seres não sencientes,
- será utilizado um número mínimo de animais no experimento
- os procedimentos foram planejados de modo a minimizar o desconforto provocado ao animal durante o experimento.

Este estudo não é desnecessariamente duplicativo, tem mérito científico e a equipe que participa desta atividade foi treinada e é competente para executar os procedimentos descritos nesse protocolo.

Comprometo-me a informar, por ofício, a CEUA/UFRGS eventuais alterações significativas nos experimentos aqui descritos, antes da implementação das mesmas.

Tudo o que foi declarado nesse protocolo é a absoluta expressão da verdade. Estou ciente que o não cumprimento das condições aqui especificadas é de minha total responsabilidade (pesquisador principal) e que estarei sujeito às punições previstas na legislação em vigor.

LOCAL E DATA:

Porto Alegre, 2017

Assinatura do docente ou pesquisador responsável:

X



Prof.ª Dr.ª Carolina Bremm

Assinatura dos componentes da equipe:

X

Prof. Dr. Paulo Cesar de Faccio Carvalho

X

Prof. Dr. Tales Tiecher

X

Prof.^a Dr.^a Amanda Posselt Martins

X

Dr. Jean Victor Savian

X

M. Sc. Gustavo Duarte Farias

X

M. Sc. Luis Gustavo Denardin

X

Eng. Ag. Lucas Aquino Alves

X

Dionatan Filippi

X

Lóren Pacheco Duarte

X

Luciano Pinzon Brauwens

X

Mateus Westerhofer Goulart

X

Adão Luis Ramos Dos Santos