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# Soil Properties and Plant Biomass Production in Natural Rangeland Management Systems

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**ABSTRACT:** Improper management of rangelands can cause land degradation and reduce the economic efficiency of livestock activity. The aim of this study was to evaluate soil properties and quantify plant biomass production in four natural rangeland management systems in the Santa Catarina Plateau (Planalto Catarinense) of Brazil. The treatments, which included mowed natural rangeland (NR), burned natural rangeland (BR), natural rangeland improved through the introduction of plant species after harrowing (IH), and natural rangeland improved through the introduction of plant species after chisel plowing (IC), were evaluated in a *Nitossolo Bruno* (Nitisol). In the improved treatments, soil acidity was corrected, phosphate fertilizer was applied, and intercropped annual ryegrass (*Lolium multiflorum*), velvet grass (*Holcus lanatus*), and white clover (*Trifolium repens*) were sown. Management systems with harrowed or chisel plowed soil showed improved soil physical properties; however, the effect decreased over time and values approached those of burned and mowed natural rangelands. Natural rangeland systems in the establishment phase had little influence on soil organic C. The mowed natural rangeland and improved natural rangeland exhibited greater production of grazing material, while burning the field decreased production and increased the proportion of weeds. Improvement of the natural rangelands increased leguminous biomass for pasture.

**Keywords:** natural rangeland improvement, forage production, weeds.

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## INTRODUCTION

The Araucaria Highland Plateau (Campos de Altitude do Planalto das Araucárias) is located in the south of Brazil and constitutes one of the region's largest ecological areas. The range areas present in this ecosystem represent the main forage resource used for cattle raising (Nabinger et al., 2000), with range-fed animal production considered as one of the main economic activities.

Natural grazing lands in the Santa Catarina Plateau are characterized by prominent seasonality regarding forage production. These rangelands are basically formed by hot season species, which stop growing with the arrival of the cold season and die in the frost. Limited biomass production results in overgrazing during the winter period, which implies a reduction in soil cover and damage to soil physical properties (Bertol et al., 1998). In addition, field burning to renew grazing lands is a common practice at this time of the year, inducing the mineralization of organic matter and increasing nutrient availability in the soil surface in the short term; this effect is lost in the long-term period (Redin et al., 2011) due to nutrient loss, predominantly caused by water erosion (Bertol et al., 2011).

However, systems that offer alternatives to traditional management of grazing lands are little used in the Santa Catarina Plateau region, although they can reduce environmental and economic risks arising from this activity. The technique of improving a natural rangeland by introducing cold season species, along with acidity correction and soil amendment, appears to be an alternative for increasing field productivity, since forage production from the introduced species occurs in the period of native rangeland senescence (Córdova et al., 2004). Besides contributing to reduction in forage deficit, which is characterized by an accentuated decline in production of grazing material, this technique can improve fertility and preserve native plant species (Boldo et al., 2006).

Native rangelands require management techniques that reduce soil compaction and allow for appropriate development of forage, which entails soil tillage in some situations; one such situation is the introduction of plant species for field improvement. The recovery of degraded grazing lands to improve soil physical properties can be carried out with the assistance of mechanical practices, such as chisel plowing, which favors plant root development and increases infiltration and water availability in the soil (Colet et al., 2009; Silva and Minato, 2014). While natural rangelands need to be preserved, it is necessary to make them more productive and profitable; otherwise they may be replaced by other activities.

The hypothesis of this study is that burning of natural rangelands degrades the soil and reduces rangeland production compared to mowed natural rangelands and improved natural rangelands. The objective of this study was to evaluate the changes caused by different natural rangeland management systems in the experimental implementation phase in regard to the physical and chemical properties of a Nitisol and production of grazing material and weeds, as well as the proportion of grasses and leguminous plants in the botanical composition of the grazing material.

## MATERIALS AND METHODS

The experiment was conducted from May 2012 to November 2013 in the municipality of Lages, SC, Brazil, located in the south of the Santa Catarina Plateau (27° 54' 34" S and 50° 20' 42" W, with average altitude of 900 m). Climate in the region is the Cfb type according to the Köppen classification system - mesothermal humid subtropical, with warm summers and frequent and severe frosts in the winter (Alvares et al., 2013). The annual average maximum temperature is 21.7 °C, and the annual average minimum temperature is 11.5 °C. The soil is a *Nitossolo Bruno* (Embrapa, 2004), or a Nitisol (IUSS Working Group WRB, 2014), with a clayey texture (Table 1).

**Table 1.** Physical and chemical properties of the soil from the experimental area, in different layers

| Layer | Sand | Silt | Clay | Bd | pH($H_2O$) | P | K | $Ca^{2+}$ | $Mg^{2+}$ | $Al^{3+}$ | TOC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m | g $kg^{-1}$ | | | Mg $m^{-3}$ | | mg $kg^{-1}$ | | $cmol_c$ $kg^{-1}$ | | | g $kg^{-1}$ |
| 0.00-0.025 | 165 | 345 | 490 | 1.03 | 4.75 | 0.80 | 120.50 | 3.25 | 2.65 | 0.96 | 37.20 |
| 0.025-0.05 | 155 | 320 | 525 | 1.15 | 4.75 | 0.80 | 77.50 | 3.39 | 2.59 | 2.76 | 30.70 |
| 0.05-0.10 | 155 | 280 | 565 | 1.14 | 4.85 | 0.95 | 85.50 | 3.38 | 2.64 | 2.68 | 24.25 |
| 0.10-0.20 | 145 | 280 | 575 | 1.20 | 4.85 | 1.05 | 60.50 | 3.66 | 2.37 | 3.11 | 23.35 |

Sand, silt, clay: pipette method; Bd: bulk density (Claessen, 1997); pH in water, 1:1 ratio, v/v; P and K: Mehlich-1 extractant; $Ca^{2+}$, $Mg^{2+}$, $Al^{3+}$: 1 mol $L^{-1}$ KCl extractant; H+Al: 0.5 mol $L^{-1}$ calcium acetate extractant at pH 7.0; TOC: total organic carbon (Tedesco et al., 1995).

Before setting up the treatments in July 2012, the grazing land had been managed with fire for more than 80 years. The physiognomy type in the study location is known as Coarse Grass Rangeland (*Campo Palha Grossa*), with the presence of botanical families of grasses, legumes, sedges, Melastomataceae, Verbenaceae, and Solanaceae.

The experimental unit was 10-m wide and 22-m long (220 $m^2$). The area was divided into two blocks, with four treatments and two replications per block, for a total of 16 plots. The treatments tested consisted of four methods of management of grazing lands, set up over the natural rangeland: i) burned natural rangeland (BR), with untilled soil and accumulated dry plant biomass subjected to only one burning at the beginning of the experimental period for vegetative regrowth; ii) mowed natural rangeland (NR) with untilled soil and accumulated dry plant biomass mowed only once at the beginning of the experimental period for vegetative regrowth; iii) harrowed improved natural rangeland (IH), with soil amendment through limestone application and a harrowing operation in order to establish a cold season plant species; and iv) chisel plowed improved natural rangeland (IC) , with soil amendment through limestone application and a chisel plowing operation in order to establish cold season plant species.

Soil acidity was previously corrected in May 2012 in the plots that would receive the IH and IC treatments, with application of 5 Mg $ha^{-1}$ of dolomitic limestone on the soil surface. Species were sown in July 2012, immediately after soil tillage operations (harrowing in the IH and chisel plowing in the IC). Intercropped species were the following: *Trifolium repens* (white clover), *Holcus lanatus* (velvet grass), and *Lolium multiflorum* (ryegrass), at a sowing density of 6, 16, and 40 kg $ha^{-1}$, respectively. A phosphate fertilizer (triple superphosphate - 44 % $P_2O_5$) was applied at sowing at a rate of 300 kg $ha^{-1}$, following the recommendations of CQFSRS/SC (2004). Seeds and fertilizer were broadcast using a broadcast spreader. After that, an agricultural land roller was used to increase soil/seed contact.

To establish hibernal species and to provide good natural re-sowing, all treatments were maintained without animal grazing during the evaluation period, a recommended and indispensable practice for setting up systems for improvement of native rangeland, according to Córdova et al. (2004).

Physical and chemical soil analyses were carried out 30, 120, and 330 days after initial management practices. Undisturbed soil samples were collected in metallic soil sampling rings from the 0.00-0.025, 0.025-0.05, 0.05-0.10, and 0.10-0.20 m layers for physical determination of soil bulk density (Bd), total pore volume (TP), macropores (Ma), and micropores (Mi), according to Claessen (1997). Soil in the rings were saturated, subjected to 6 kPa tension, and later dried at 105 °C. Disturbed soil samples were collected at the same depths for chemical determination of total organic carbon content in the soil (TOC) through sulfuric acid and chromic acid digestion, and determination of soil pH in water through potentiometry. The methods used were described by Tedesco et al. (1995).

Sampling for determination of dry matter yield from plant biomass was carried out at 180, 330, and 420 days after setting up the treatments. An area of 3 $m^2$ per plot was cut with a manual mower 0.07 m from the soil surface to simulate the residual height of the grazing land. The forage collected on each cutting date was weighed and botanical separation was made between the material of preferable consumption by animals (grazing material) and rejected material (weeds). A further separation was performed between grass and leguminous plants in the composition of the grazing material. Each component was packed in paper bags, dried in a laboratory oven at 65 °C until reaching constant weight, and then weighed (Gardner, 1986).

The data were subjected to analysis of variance, and the treatment averages were compared within each season by t-test ($p<0.05$).

## RESULTS AND DISCUSSION

The different systems of natural rangeland management had little influence on soil bulk density (Bd), with greater variation among treatments in the surface layer (Table 2). In the evaluation carried out after 120 days, the IC treatment showed lower Bd down to a depth of 0.05 m, which can be explained by the action of the chisel plow shanks on the soil. The IH treatment had a result similar to the NR and BR treatments, showing that harrowing caused little change in bulk density. Bulk density was similar among the treatments after 330 days, which is consistent with the results of Abreu et al. (2004) and Bordin et al. (2005), and can be explained by the soil reconsolidation that occurred between the mechanical operation and the most recent evaluation.

Soil total porosity (TP) exhibited significant differences in the 0.00-0.025 m layer after 30 and 120 days (Table 2). The IC treatment had higher TP in both evaluations, while BR had the lowest values. Working the soil through chisel plowing resulted in development of pores, even though they were restricted to the surface layer and had a transient effect, since differences among the treatments were not observed after 330 days. In the 0.00-0.025 m layer, IC provided an increase of 9.8, 7.4, and 1.2 % in TP in relation to BR at the first, second, and third evaluations, respectively. As time progressed, root action and fauna activity, in addition to soil wetting and drying cycles, reduced the differences among the treatments.

Soil macroporosity (Ma) differed among the treatments at all depths for the evaluation after 30 days (Table 2). Tilling the soil in IH and IC increased Ma compared to BR and NR. In the 0.00-0.025 m layer, the Ma values were 2.5 and 2.1 times higher than BR for IC and IH in the first evaluation, respectively, demonstrating that chiseling plowing mobilized the soil with higher intensity than harrowing. Considering the critical Ma limit ($<0.10$ $m^3$ $m^{-3}$), below which water infiltration and oxygen supply to the roots become limiting (Silva et al., 1994), after 30 days the IH and IC exhibited values above this limit down to a depth of 0.05 m, while the treatments with the absence of tillage (BR and NR) exhibited Ma lower than the critical limit. In the second and third evaluations (120 and 330 days), there was a difference between the treatments only in the 0.00-0.025 m layer, with IC having the highest Ma. Management systems in these evaluations did not differ among each other for the remaining layers, probably due to soil reconsolidation. The Ma values observed over time were above the critical limit in the second and third evaluations for all treatments in the 0.00-0.025 m layer, possibly due to beneficial plant action and soil cover that were present after setting up the treatments.

Soil microporosity (Mi) was greater in the treatments without soil tillage (BR and NR) in all layers sampled in the first evaluation (Table 2). The same treatments in the second evaluation retained a higher Mi volume, even though there was no statistical difference regarding the treatments with soil tillage (IH and IC). All treatments in the third evaluation showed similar values, except for the first layer, in which the IC had lower Mi.

**Table 2.** Soil bulk density (Bd), total porosity, macroporosity, microporosity, total organic carbon (TOC), and soil pH, in four layers for the different treatments and evaluation periods (30, 120, and 330 days)

| Treat.[(1)] | Bd (Mg m$^{-3}$) | | | Total porosity (m$^3$ m$^{-3}$) | | | Macroporosity (m$^3$ m$^{-3}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 30 d | 120 d | 330 d | 30 d | 120 d | 330 d | 30 d | 120 d | 330 d |
| | | | | | 0.00-0.025 m | | | | |
| BR | 0.95$^{ns}$ | 1.00 a | 0.90$^{ns}$ | 0.62 c | 0.62 b | 0.66$^{ns}$ | 0.090 b | 0.116 b | 0.123 b |
| NR | 1.03$^{ns}$ | 0.93 ab | 0.87$^{ns}$ | 0.64 bc | 0.65 ab | 0.69$^{ns}$ | 0.092 b | 0.144 ab | 0.145 b |
| IH | 0.99$^{ns}$ | 0.99 a | 0.84$^{ns}$ | 0.66 ab | 0.62 b | 0.68$^{ns}$ | 0.187 a | 0.130 ab | 0.162 ab |
| IC | 0.95$^{ns}$ | 0.87 b | 0.87$^{ns}$ | 0.68 a | 0.66 a | 0.67$^{ns}$ | 0.228 a | 0.191 a | 0.193 a |
| CV (%) | 6.7 | 7.9 | 6.6 | 3.2 | 3.7 | 3.0 | 21.7 | 30.8 | 16.8 |
| | | | | | 0.025-0.05 m | | | | |
| BR | 1.07 b | 1.07 ab | 1.04$^{ns}$ | 0.60$^{ns}$ | 0.59$^{ns}$ | 0.61$^{ns}$ | 0.085 bc | 0.083$^{ns}$ | 0.088$^{ns}$ |
| NR | 1.15 a | 1.10 ab | 1.06$^{ns}$ | 0.60$^{ns}$ | 0.58$^{ns}$ | 0.59$^{ns}$ | 0.068 c | 0.067$^{ns}$ | 0.062$^{ns}$ |
| IH | 1.14 a | 1.14 a | 1.03$^{ns}$ | 0.60$^{ns}$ | 0.57$^{ns}$ | 0.61$^{ns}$ | 0.106 ab | 0.065$^{ns}$ | 0.084$^{ns}$ |
| IC | 1.10 ab | 1.01 b | 1.02$^{ns}$ | 0.61$^{ns}$ | 0.60$^{ns}$ | 0.63$^{ns}$ | 0.131 a | 0.101$^{ns}$ | 0.107$^{ns}$ |
| CV (%) | 3.1 | 6.7 | 6.2 | 2.3 | 3.8 | 3.8 | 17.2 | 39.6 | 30.3 |
| | | | | | 0.05-0.10 m | | | | |
| BR | 1.09$^{ns}$ | 1.11$^{ns}$ | 1.08$^{ns}$ | 0.57$^{ns}$ | 0.55$^{ns}$ | 0.57$^{ns}$ | 0.060 ab | 0.050$^{ns}$ | 0.068$^{ns}$ |
| NR | 1.14$^{ns}$ | 1.12$^{ns}$ | 1.08$^{ns}$ | 0.57$^{ns}$ | 0.55$^{ns}$ | 0.58$^{ns}$ | 0.050 b | 0.050$^{ns}$ | 0.083$^{ns}$ |
| IH | 1.15$^{ns}$ | 1.13$^{ns}$ | 1.08$^{ns}$ | 0.56$^{ns}$ | 0.55$^{ns}$ | 0.56$^{ns}$ | 0.070 ab | 0.049$^{ns}$ | 0.068$^{ns}$ |
| IC | 1.14$^{ns}$ | 1.13$^{ns}$ | 1.07$^{ns}$ | 0.56$^{ns}$ | 0.56$^{ns}$ | 0.57$^{ns}$ | 0.078 a | 0.066$^{ns}$ | 0.057$^{ns}$ |
| CV (%) | 2.7 | 2.7 | 4.3 | 2.1 | 5.0 | 2.7 | 27.6 | 36.1 | 19.1 |
| | | | | | 0.10-0.20 m | | | | |
| BR | 1.14$^{ns}$ | 1.12$^{ns}$ | 1.10$^{ns}$ | 0.58$^{ns}$ | 0.54$^{ns}$ | 0.57$^{ns}$ | 0.056 bc | 0.051$^{ns}$ | 0.066$^{ns}$ |
| NR | 1.20$^{ns}$ | 1.16$^{ns}$ | 1.13$^{ns}$ | 0.56$^{ns}$ | 0.55$^{ns}$ | 0.57$^{ns}$ | 0.035 c | 0.049$^{ns}$ | 0.076$^{ns}$ |
| IH | 1.18$^{ns}$ | 1.16$^{ns}$ | 1.09$^{ns}$ | 0.56$^{ns}$ | 0.54$^{ns}$ | 0.57$^{ns}$ | 0.073 ab | 0.045$^{ns}$ | 0.061$^{ns}$ |
| IC | 1.16$^{ns}$ | 1.14$^{ns}$ | 1.08$^{ns}$ | 0.58$^{ns}$ | 0.58$^{ns}$ | 0.57$^{ns}$ | 0.089 a | 0.078$^{ns}$ | 0.065$^{ns}$ |
| CV (%) | 4.6 | 3.5 | 4.9 | 4.0 | 4.1 | 3.1 | 33.3 | 34.5 | 12.7 |
| | Microporosity (m$^3$ m$^{-3}$) | | | TOC (g kg$^{-1}$) | | | pH($H_2O$) | | |
| | | | | | 0.00-0.025 m | | | | |
| BR | 0.53 a | 0.50$^{ns}$ | 0.54 a | 37.4$^{ns}$ | 44.2$^{ns}$ | 41.0$^{ns}$ | 4.8 b | 5.0 bc | 4.8 b |
| NR | 0.55 a | 0.50$^{ns}$ | 0.55 a | 35.8$^{ns}$ | 44.7$^{ns}$ | 43.2$^{ns}$ | 4.9 b | 4.9 c | 4.8 b |
| IH | 0.48 b | 0.49$^{ns}$ | 0.51 ab | 36.9$^{ns}$ | 39.8$^{ns}$ | 40.6$^{ns}$ | 5.9 a | 5.4 ab | 5.6 a |
| IC | 0.45 b | 0.47$^{ns}$ | 0.48 b | 37.7$^{ns}$ | 41.6$^{ns}$ | 42.3$^{ns}$ | 5.9 a | 5.7 a | 5.5 a |
| CV (%) | 4.6 | 6.4 | 5.1 | 4.5 | 7.9 | 4.7 | 7.0 | 4.9 | 2.9 |
| | | | | | 0.025-0.05 m | | | | |
| BR | 0.52 a | 0.51$^{ns}$ | 0.52$^{ns}$ | 31.7$^{ns}$ | 32.5$^{ns}$ | 33.3 b | 5.1$^{ns}$ | 4.8$^{ns}$ | 4.8 b |
| NR | 0.54 a | 0.51$^{ns}$ | 0.53$^{ns}$ | 29.5$^{ns}$ | 34.2$^{ns}$ | 36.8 a | 5.3$^{ns}$ | 4.8$^{ns}$ | 4.8 b |
| IH | 0.49 b | 0.50$^{ns}$ | 0.52$^{ns}$ | 29.9$^{ns}$ | 32.9$^{ns}$ | 35.5 a | 5.1$^{ns}$ | 4.7$^{ns}$ | 4.8 b |
| IC | 0.48 b | 0.50$^{ns}$ | 0.52$^{ns}$ | 29.9$^{ns}$ | 36.7$^{ns}$ | 35.7 a | 5.3$^{ns}$ | 5.0$^{ns}$ | 5.2 a |
| CV (%) | 2.6 | 2.8 | 3.2 | 6.2 | 9.8 | 3.8 | 4.5 | 3.9 | 4.1 |
| | | | | | 0.05-0.10 m | | | | |
| BR | 0.51 a | 0.50$^{ns}$ | 0.51$^{ns}$ | 27.7$^{ns}$ | 30.4$^{ns}$ | 30.9$^{ns}$ | 5.1$^{ns}$ | 4.6 b | 4.8$^{ns}$ |
| NR | 0.52 a | 0.50$^{ns}$ | 0.50$^{ns}$ | 26.8$^{ns}$ | 28.3$^{ns}$ | 28.8$^{ns}$ | 4.9$^{ns}$ | 4.6 b | 4.8$^{ns}$ |
| IH | 0.49 b | 0.50$^{ns}$ | 0.49$^{ns}$ | 26.4$^{ns}$ | 28.5$^{ns}$ | 30.8$^{ns}$ | 5.1$^{ns}$ | 5.0 a | 4.7$^{ns}$ |
| IC | 0.48 b | 0.49$^{ns}$ | 0.51$^{ns}$ | 27.4$^{ns}$ | 28.9$^{ns}$ | 30.5$^{ns}$ | 5.1$^{ns}$ | 4.9 ab | 4.7$^{ns}$ |
| CV (%) | 2.8 | 3.7 | 2.7 | 5.0 | 5.7 | 3.8 | 4.9 | 3.6 | 2.2 |
| | | | | | 0.10-0.20 m | | | | |
| BR | 0.53 a | 0.49$^{ns}$ | 0.50$^{ns}$ | 24.2$^{ns}$ | 27.0$^{ns}$ | 27.6$^{ns}$ | 4.9$^{ns}$ | 4.8$^{ns}$ | 4.7$^{ns}$ |
| NR | 0.52 a | 0.50$^{ns}$ | 0.49$^{ns}$ | 23.4$^{ns}$ | 27.1$^{ns}$ | 25.9$^{ns}$ | 4.8$^{ns}$ | 4.7$^{ns}$ | 4.7$^{ns}$ |
| IH | 0.49 b | 0.50$^{ns}$ | 0.50$^{ns}$ | 23.8$^{ns}$ | 26.5$^{ns}$ | 26.1$^{ns}$ | 4.9$^{ns}$ | 4.7$^{ns}$ | 4.8$^{ns}$ |
| IC | 0.49 b | 0.50$^{ns}$ | 0.51$^{ns}$ | 24.9$^{ns}$ | 26.7$^{ns}$ | 26.6$^{ns}$ | 5.1$^{ns}$ | 4.7$^{ns}$ | 4.8$^{ns}$ |
| CV (%) | 3.5 | 3.3 | 2.6 | 4.2 | 3.9 | 10.4 | 4.6 | 4.4 | 1.3 |

[(1)] BR: burned natural rangeland; NR: mowed natural rangeland; IH: improved natural rangeland with harrowing; IC: improved natural rangeland with chisel plowing. Means followed by the same letter in the column do not differ among themselves by the t-test (p<0.05). $^{ns:}$ effect of the treatments not significant by analysis of variance (p<0.05).

The highest TP, Ma, and Mi changes in the treatments with soil tillage in comparison to those without tillage occurred in the 0.00-0.025 m layer, which suggests that mechanical tillage is more efficient for the soil surface. In addition, soil tillage resulted in sharper changes in Ma and Mi than in TP. This suggests that part of the Mi was converted to Ma through the use of tillage equipment, in agreement with Camara and Klein (2005). Although chisel plowing showed positive effects, there is considerable variability regarding the longevity of its effects in the soil (Twomlow et al., 1994; Evans et al., 1996). As observed throughout the present evaluation, the effect of chisel plowing declined over time, since reconsolidation increases with the cumulative volume of rainfall and with soil wetting and drying cycles (Busscher et al., 2002).

Soil total organic carbon (TOC) contents showed little variation among the treatments (Table 2). A statistical difference was observed in the third evaluation (330 days), in which BR had lower TOC in the 0.025-0.05 m layer. In addition, there was a decrease in these contents as determination went deeper into the soil profile, which was also observed in the study of Castro Filho et al. (2002). Production systems without animal trampling and intense soil tillage did not show significant differences in TOC content (Bavoso et al., 2010), just as the results obtained in this experiment showed. This can be explained by the fact that these experiments involved experiments that were recently set up.

The effects of limestone applied on the soil surface in the IH and IC treatments were detected in the soil profile down to a depth of 0.10 m (Table 2). For these treatments, the highest pH values were identified in the 0.00-0.025 m soil layer in all evaluations. Soil tillage in IC through the action of the chisel plow shafts allowed the soil amendment material to disperse throughout the soil profile and differentiate the IC from the other treatments in the 0.025-0.05 m layer, particularly in the third evaluation. This was probably due to the physical characteristics provided by the mechanical action of the chisel plow shafts, enabling mechanical displacement of fine limestone particles via descending water movement in the profile and also through the product of limestone reactions (Cahn et al., 1993). In the remaining layers, the soil pH did not differ among treatments, except for the 0.05-0.10 m layer in the second evaluation, in which the pH values were higher in IH and IC. This probably occurred due to the depth limitation of the equipment, as well as the reaction time of the soil amendment material.

Plant biomass production of grazing material varied among the treatments in all evaluations (Table 3). Production from the first harvest, after 180 days, was higher in the IH and NR treatments and differed from BR. The chisel-plow-improved natural rangeland showed intermediate production, and did not differ from any other treatment. Average production of grazing material in the IH and NR treatments was seven times the production in BR and two times the production in IC. Except for BR, all remaining treatments had statistically similar production of grazing material, which can be explained by the low rainfall index that occurred from set-up of the experiment until establishment of the species. In a study performed with natural rangeland systems on the Santa Catarina Plateau, Córdova et al. (2012) observed production greater than 4,000 kg $ha^{-1}$ for an equivalent evaluation period, differing from the results obtained in the current experiment, which had values in NR similar to the improved treatments (IH and IC), probably due to better adaptation of native species to the drought that occurred at the beginning of the experiment.

The initial development period for the species used in the grazing land improvement systems is considered crucial for their feasibility. The need for chemical and physical adequacy of the soil and enough water for plant development are important points that determine success in establishing the species (Córdova et al., 2004). The period between setting up this experiment and the first evaluation of forage production (180 days) was characterized by drought, which contributed to reduced production in IC in comparison to NR and IH. Such a response can be explained as a result of working the soil more and its consequent exposure, caused by chisel plowing. This allows for greater variation in soil temperature and consequent water evaporation (Bragagnolo and Mielniczuck, 1990).

**Table 3.** Production of plant biomass of grazing material, weeds, and total dry matter, and the composition of leguminous plants and grasses in the grazing material for different treatments and evaluation periods

| Treat.[(1)] | Plant biomass | | | Grazing material composition | |
|---|---|---|---|---|---|
| | Grazing material | Weeds | Total | Leguminous | Grasses |
| | kg ha$^{-1}$ | | | | |
| | | | 180 days | | |
| BR | 358.2 b | 553.2 a | 911.4 b | 0.0 b | 358.2 b |
| NR | 2,424.2 a | 319.2 ab | 2,743.4 a | 0.0 b | 2,424.2 a |
| IH | 2,572.0 a | 192.3 b | 2,764.3 a | 105.1 a | 2,466.9 a |
| IC | 1,208.5 ab | 181.5 b | 1,390.0 b | 7.2 b | 1,201.3 ab |
| CV (%) | 54.9 | 68.9 | 42.0 | 61.0 | 59.0 |
| | | | 330 days | | |
| BR | 25.9 c | 26.3 a | 52.3 b | 0.1 b | 25.8 b |
| NR | 69.3 b | 5.7 b | 74.9 b | 0.2 b | 69.1 a |
| IH | 67.9 b | 5.7 b | 73.7 b | 7.1 b | 60.9 ab |
| IC | 126.8 a | 5.1 b | 131.9 a | 39.3 a | 87.5 a |
| CV (%) | 40.0 | 54.5 | 41.6 | 76.3 | 40.9 |
| | | | 420 days | | |
| BR | 81.3 c | 22.2 a | 103.5 b | 0.1 b | 81.2 b |
| NR | 171.4 bc | 5.7 b | 177.0 b | 0.1 b | 171.3 a |
| IH | 180.5 b | 6.9 b | 187.4 b | 17.4 b | 163.1 a |
| IC | 304.7 a | 12.2 ab | 316.9 a | 86.3 a | 218.4 a |
| CV (%) | 33.5 | 69.7 | 31.2 | 71.6 | 33.1 |
| | | | Sum of the evaluations | | |
| BR | 465.5 b | 601.7 a | 1,067.2 b | 0.2 b | 465.3 b |
| NR | 2,664.9 a | 330.5 ab | 2,995.3 a | 0.3 b | 2,664.6 a |
| IH | 2,820.5 a | 204.9 b | 3,025.4 a | 129.6 a | 2,690.9 a |
| IC | 1,640.0 ab | 198.8 b | 1,838.8 ab | 132.8 a | 1,507.2 ab |
| CV (%) | 50.4 | 66.7 | 37.0 | 62.0 | 50.2 |

[(1)] BR: burned natural rangeland; NR: mowed natural rangeland; IH: improved natural rangeland with harrowing; IC: improved natural rangeland with chisel plowing. Means followed by the same letter in the column do not differ among themselves by the t-test ($p<0.05$).

In the evaluations performed at 330 and 420 days, the dry matter production of grazing material in the BR treatment was inferior to the production in the remaining treatments, and was 79.6 and 73.3 % smaller than production in the IC treatment in the second and third evaluations, respectively. For those same evaluations, IC provided higher production of grazing material than NR and IH, which showed the positive effect from chisel plowing after the second evaluation. Considering total production of grazing material (i.e., the sum of the three samplings), the NR, IH, and IC treatments had the highest values, and although the BR treatment produced an amount which was 71.6 % smaller than the IC treatment, they did not differ statistically (Table 3).

The BR treatment had higher weed production in all evaluations (Table 3), with proportions of 61, 50, and 21.5 % of the total plant biomass produced in the first, second, and third evaluations, respectively. In contrast with the percentage of weeds in BR, the IC treatment had 13, 3.9, and 3.8 %; IH had 7, 7.7, and 3.7 %, and NR had 11.6, 7.6, and 3.2 % undesirable plants in the three consecutive evaluations. The highest occurrence of weeds found in the improved and mowed natural rangelands (IC, IH, and NR) was of the *Baccharis* genus (gorse and brooms). On the other hand, in the burned field (BR), the genera *Baccharis* (gorse and brooms), *Eryngium* (eryngo), and *Pteridium* (ferns) predominated. The elevated weed percentage in the BR treatment can be explained due to the adaptation of these plants to conditions of field management with fire (Fontaneli and Jacques, 1988). Burning favors weeds by not affecting their structure, which is often underground, in comparison to most of the pasture species that have a large number of buds on the soil surface. Additionally, fire opens up spaces in the soil surface and favors rapid weed development.

Degraded grazing lands provide an opportunity for colonization of pioneer plants, searched for by animals only when the main forage is scarce (Dias-Filho, 2003). These are considered weeds because they generally do not have the nutritional value required for animal development. Signs of degradation of grazing lands include a decrease in yield and an increase in the frequency of invasive species, which initially occupy soil spaces left uncovered by forage plants, and later dominate the areas still occupied by forage. The proportion of production of grazing material in relation to weeds, in the sum of the three evaluations, was 89, 93.2, and 89.2 % in NR, IH, and IC, respectively, while BR had a proportion of 43.6 %. The percentage of weeds in BR was approximately 5 times the percentage of the other treatments.

Systems with improvement of the natural rangeland provided a significant increase in the amount of leguminous plants in the botanical composition of the grazing material during the experimental period, due to the introduction of white clover (*Trifolium repens*), along with acidity correction and improved soil fertility, which favor the development of leguminous plants. Such plants were not observed in the grazing lands with the NR and BR treatments at the first sampling after 180 days; they occurred only in the remaining evaluations, although in very low amounts (Table 3). A few specimens of *Trifolium riograndense* (little clover) were found in those treatments. In the total of the evaluations, the proportion of leguminous plants in comparison to grasses in composition of the pasture species was less than 0.01 % in the NR and BR treatments, while the proportion was 4.6 and 8.1 % in the IH and IC treatments, respectively.

The introduction of leguminous plants, present only in the improved treatments (IH and IC), resulted in improved quality as grazing lands because the rangelands in the region are characterized by a predominance of native grasses with low quality and little potential for growth in the cold season. In a study performed by Heringer and Jacques (2002a), in the absence of the fire management practice, a reduction in uncovered soil was observed as an effect of fertilization of native rangeland, as well as lower participation of grasses of low nutritional value and undesirable plants in the botanical composition. Acidity correction, soil fertilization, and mowing can favor species of higher quality for grazing, while the use of fire favors species of lower quality and decreases floral richness (Heringer and Jacques, 2002b).

Common in the Santa Catarina Plateau region, the practice of burning a fast and low-cost method for clearing an area, although burning results in soil degradation. Management of natural rangelands through the use of mowing processes appears to be an alternative for elimination of weeds and remaining dry material. However, since mowing generates costs in terms of labor and equipment, this practice is rarely used as a management practice.

## CONCLUSIONS

Harrowing or chisel plowing natural rangelands improves soil physical properties, although the effect decreases over time and the values begin to approach those of burned natural rangelands and mowed natural rangelands. Natural rangeland management systems in the establishment phase have little influence on the organic carbon content of the Nitisol. Surface liming to improve natural rangelands leads to an increase in soil pH down to a depth of 0.10 m.

Burning of natural rangeland results in reduced production of grazing material and a higher proportion of weeds compared to mowed natural rangelands or improved natural rangelands. The improvement of natural rangelands with acidity correction and increased soil fertility, as well as the introduction of cold season species, increases the production of leguminous plants in the grazing land in comparison to mowed natural rangelands and burned natural rangelands.

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