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Forage production in a natural grassland with limestone and phosphorus dosages

Produção de forragem em pastagem natural submetida a aplicações de calcário e fósforo

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Abstract

The objective of this study was to assess forage production in a natural grassland by applying different doses of limestone and phosphorus, and the influence of these applications on soil profile. The treatments consisted of the application of limestone doses of 0.0, 7.2, and 14.4 t ha^{-1} and phosphorus doses of 0, 35, 70, and 140 kg of P_2O_5 ha^{-1} on the soil surface. The experiment was conducted in a randomized complete block design with split-plots and three replications. The limestone doses were distributed in the main plot and applied only at the beginning of the experiment, whereas the phosphorus doses were distributed in the subplots with subsequent annual maintenance applications. Was used a ruler (cm) for monitoring the growth of pastures and, when grasses reached an average height of 20 cm, forage samples were collected in each subplot and botanical and morphological components were separated and dried until a constant weight was achieved. In the third and fourth assessment years, soil samples were collected in the 0-5, 5-10, 10-15, and 15-20-cm layers to evaluate the influence of treatments on the chemical properties of the soil. The variables analyzed were related to the production of several components, including fodder, native grasses, leguminous plants, unwanted plants, and dead material, in addition to soil properties such as pH, exchangeable aluminum concentration, and base saturation. There was no interaction between the limestone and phosphorus treatments. The effect of limestone doses on forage production was assessed in the third year, and, in the following year, the intermediate dose of limestone (7.2 t ha^{-1}) produced the highest yield (2,316.1 kg of dry matter [DM] of forage ha^{-1}). The increase in phosphorus doses increased forage production in the second year, and reached yields of up to 2,232 Kg DM ha^{-1} in the fourth year. In summary, the production of natural pastures was enhanced by the application of 25% of the recommended dose of limestone (7.2 t ha^{-1}), and by the application of 50% of the recommended dose of phosphorus (70 kg P_2O_5 ha^{-1}). The increase in limestone doses directly affected the chemical properties of the soil by decreasing acidity and exchangeable aluminum, and increasing base saturation, even in deeper layers (0-20 cm). The increase in phosphorus doses did not increase the mobility of this nutrient in the deeper layers of the soil (10-20 cm), and the effects were restricted to a depth of up to 10 cm.

Key words: Native land. Native grasses. Native leguminous plants. Natural pasture. Forage production.

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Resumo

O objetivo deste trabalho foi avaliar a produção de forragem em pastagem natural submetida a doses superficiais de calcário e fósforo e a influência dessas aplicações ao longo do perfil do solo. Os tratamentos consistiram da aplicação de doses superficiais de calcário equivalentes a 0,0; 7,2 e 14,4 $t.ha^{-1}$ e de fósforo equivalentes a 0; 35; 70 e 140 kg de P_2O_5 ha^{-1}. O experimento foi conduzido de acordo com um delineamento em blocos completos casualizados com parcelas subdivididas e três repetições. As doses de calcário foram distribuídas na parcela principal e aplicadas unicamente no início do experimento enquanto que as doses de fósforo foram distribuídas nas subparcelas com posteriores aplicações anuais de manutenção. O acompanhamento do crescimento dos pastos foi realizado por meio de uma régua graduada em centímetros e, quando os pastos atingiam altura média de 20 cm, eram coletadas amostras de forragem de cada subparcela e posteriormente os componentes botânicos e morfológicos eram separados e secos até atingirem peso constante. No 3° e 4° ano de avaliação foram coletadas amostras de solo nas camadas de 0-5, 5-10, 10-15 e 15-20 cm de profundidade para verificar a influência dos tratamentos nos atributos químicos do solo. As variáveis analisadas envolveram desde a produção de forragem, de gramíneas e leguminosas nativas, de plantas indesejáveis e de material morto e atributos do solo como pH, concentração de alumínio trocável e saturação por bases. Não houve interação entre os tratamentos de calcário e fósforo. O efeito das doses de calcário sobre a produção de pastagem natural ocorreu a partir do 3º ano e, no ano seguinte, a dose intermediária do corretivo (7,2 $t.ha^{-1}$) foi responsável pelas maiores produtividades (2.316,1 kg de MS de $forragem.ha^{-1}$). As crescentes doses de fósforo aumentaram a produção de forragem a partir do 2° ano, atingindo produções de até 2.232 kg $MS.ha^{-1}$ no 4° ano. A produção de pastagens naturais é potencializada com a aplicação de 25% da dose recomendada de calcário (7,2 $t.ha^{-1}$) associada a 50% da recomendação para a aplicação de fósforo (70 kg $P_2O_5.ha^{-1}$). Doses crescentes de calcário influenciam diretamente os atributos químicos do solo, diminuido a acidez e alumínio trocável e aumentando a saturação por bases mesmo em camadas mais profundas (0-20 cm). Doses crescentes de fósforo não foram capazes de aumentar a mobilidade deste nutriente em camadas mais profundas do solo (10-20 cm), restringindo seus efeitos na camada de até 10 cm de profundidade.

Palavras-chave: Campo nativo. Gramíneas nativas. Leguminosas nativas. Pastagem natural. Produção de forragem.

Introduction

In the mid-1990s, the natural pasturelands of Santa Catarina totaled approximately 1.3 million hectares, and 60% of this area was concentrated in the Plateau of Santa Catarina (IBGE, 1996). However, it is estimated that more than 400 thousand hectares of this ecosystem have been replaced with grain crops and forest plantations (CÓRDOVA et al., 2012). However, even with these restrictions, natural pasturelands are of great importance in livestock production systems and provide the main food source of cattle in Santa Catarina.

Livestock production systems in natural pasturelands are traditionally extensive, with low stocking rates (between 0.3 and 0.4 AU/ha^{-1}) and annual productivity of 60 to 70 kg of live weight per hectare (CARVALHO et al., 2006). Maraschin (2009) reported that these rates are below the production potential of pasturelands in southern Brazil owing to several factors. For example, I) Reduction of forage production in the cold season, during which C4 metabolism genera (e.g., *Schizachyrium*, *Paspalum*, *Axonopus*, *Eragrostis*, *Andropogon*) and some C3 metabolism species (e.g., *Briza*, *Coelorachis*, *Danthonia*, *Calamagrostis*) practically cease growth due to low temperatures and frost; II) Restrictions related to the chemical and physical properties of the pasture soil (low natural fertility, high acidity and aluminum content, rugged relief, stony and rocky protrusions); and III) The lack of adoption of appropriate techniques for the management of pasture.

Therefore, it seems plausible that, under certain conditions, human actions can increase the yield potential of pasturelands. These involve pasture management practices (paddock subdivisions, correct choice of stocking method, control of undesirable plants, and deferred grazing), as well as the modification of the acidity and nutrient supply in the soil.

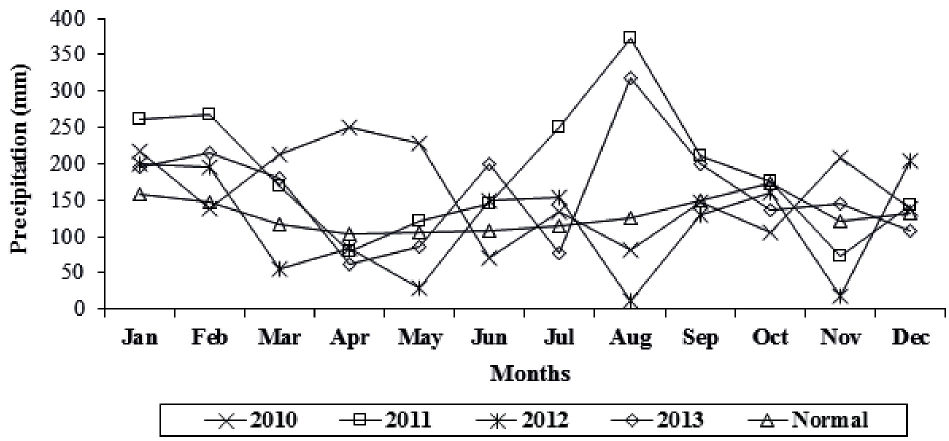
Among the management techniques aimed at rectifying the problems of acidity and low fertility typical of pasture soils, liming and fertilization have been widely used to increase productivity (POOZESH et al., 2010). In this, limestone application is highly recommended to improve the chemical, physical, and microbiological qualities of the soil.

The correct supplementation of nutrients via fertilization is essential to increase primary production of pasturelands. Phosphorus deficiency reduces plant growth, being this nutrient the second most limiting for plant production (JOUANY et al., 2004; CHIEN et al., 2011). Therefore, considering the deficiencies of pasture soils and the need to increase productivity of natural pasturelands via management practices, the aims of this study were to evaluate (i) forage production using different doses of limestone and phosphorus on the soil surface, and (ii) the influence of such applications on soil chemical properties.

Material and Methods

The experiment was conducted in the city of Lages, Santa Catarina, from January 2010 to December 2013, in a natural pasture area with a predominance *Schizachyrium tenerum* Nees. The climate, according to the Köppen classification, is Cfb subtropical climate with mild summers and a relatively even rainfall distribution (Figure 1). The soil was classified as a mixture of Haplumbrepts and Bruno Nitosol (EMBRAPA, 2006). The experimental area is located at an altitude of 1,140 m, latitude 28° 01′30.79″S, and longitude 50° 25′03.13″W.

Figure 1. Accumulated monthly rainfall during the study period.



Source: Epagri-Weather station of the Experimental Station of Lages, state of Santa Catarina, Brazil.

The treatments consisted of the application of different doses of limestone (0.0, 7.2, and 14.4 t ha^{-1}) and phosphorus (0, 35, 70, and 140 kg P_2O_5 ha^{-1}) on the soil surface. The dolomitic limestone used had a total power of neutralization (PRNT) of 60%, and the doses corresponded to 0, 25%, and 50% of the recommended amount for conventional cultivation, as described by the Chemical Commission and Soil Fertility - RS/SC (CQFS-RS/SC, 2004). Phosphorus was applied in the form of triple superphosphate and doses corresponded to 0, 25%, 50%, and 100% of the recommended amount for the conventional intercropping cultivation of grasses and cool-season leguminous plants described by CQFS-RS/SC (CQFS-RS/SC, 2004). The recommended application of limestone and phosphorus was based on the chemical properties of the soil before the start of the experimental protocol (Table 1).

Table 1. Chemical properties of soil layers of the experimental area before the implementation of the experimental protocol.

Depth	Clay	pH-H_2O	Index	P	K	M.O.	Al	Ca	Mg	(V%)
(cm)	(%)	(1:1)	SMP	(mg dm^{-3})		(%)	(cmol$_c$ dm^{-3})			
0-5	47	4,3	4,5	5,4	217	5,3	2,81	3,11	2,41	19,94
5-10	54	4,1	4,5	5,1	54	4,8	7,88	1,98	1,61	13,25
10-15	57	4,0	4,3	4,9	94	4,6	5,48	1,53	1,12	8,60
15-20	57	3,9	4,3	7,0	68	4,3	6,35	1,27	0,77	6,73

The experiment was conducted using a randomized complete block design with split-plots and three replications. The size of the subplots was 18 m² (6 × 3 m) with borders of 1 m², totaling 4 m² of usable area. The limestone doses were distributed in the main plot and applied only in February 2010. The phosphorus doses were distributed in the subplots in July 2010, and subsequently, annual maintenance applications were made (always after the last biomass sampling in the cold season) equivalent to 30% of the recommended base fertilization for phosphorus according to CQFS (CQFS-RS/SC). Crop production estimates were obtained by collecting samples containing the total biomass in the usable area of each subplot (4 m²) at a height of 8 cm from the ground. These samples were weighed and then subsampled for the performance of the botanical and morphological separation of native grasses, native leguminous plants, undesirable plants, and dead material. Each component was placed in a forced ventilation air oven at 65 °C until constant weight was achieved. The samples were collected and processed in different periods in the first year (November 30, 2010; January 11, 2011), second year (April 5, 2011; August 31, 2011; January 4, 2012), third year (March 13, 2012; August 22, 2012; December 6, 2012), and fourth year (March, 22, 2013; September 5, 2013; June 12, 2013).

The criterion used in the experimental handling of collected material was a pasture height of 20 cm as the average height of three points in each subplot measured with a ruler. After sample collection, sampling areas were subjected to cattle grazing for a period of 3-5 days to eliminate any interference of the border in forage production and to promote cattle treading and grazing in the area.

The chemical properties of the soil were analyzed between August 2012 and September 2013. Soil samples were collected with augers with a diameter of 10 cm and in soil depths of 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm and then sent for analysis at the Soil Laboratory of UDESC/CAV in Lages, Santa Catarina. Soil characteristics between the third and fourth year were presented as the average values of acidity (pH in water), exchangeable aluminum, base saturation (V%), and phosphorus concentration.

The results were analyzed by analysis of variance. The effect of treatments was analyzed using orthogonal polynomial contrasts (linear and quadratic) at a significance level of 10%.

Results and Discussion

Dry matter (DM) production was lower than expected for a natural pasture (Tables 2 and 3), which can be attributed to the effect of cutting height used to estimate the availability of DM (8 cm above the ground) and the long sampling and sample-processing intervals (~105 days, which was long enough for the senescence of a portion of the forage material accumulated during the growth period).

Because of the absence of interaction between limestone and phosphorus levels for the attributes evaluated, their effects will be discussed separately. Forage production, primarily determined by the production of native grasses, was not influenced by the different doses of limestone in the first and second year of assessment. These results corroborate those described by Ramos (1998) for crops in the region of Lages, Santa Catarina, and reinforce the need for a period of time long enough to allow the limestone to react with acidity sources in the soil. However, increasing limestone doses increased the production of native grasses linearly in the third year of assessment and quadratically in the fourth year of assessment, and affected forage production directly (Table 2). The positive linear relationship between grass production and limestone doses in the third year is possibly due to the effect of limestone on soil acidity. In the fourth year, the high doses of limestone had no farther effect on grass production due to possible saturation of the soil with limestone.

Table 2. Annual production of dry matter (DM; kg ha^{-1}) in each botanical and morphological category selected for the assessment of the response of the soil surface to the use of different doses of limestone (t ha^{-1}).

Dosages of limestone (t ha^{-1})	Production of DM (kg ha^{-1})					
	Native grasses	Native leguminous plants	Undesirable plants	Dead material	Forage	Total DM
			First year			
0	672,6	0,8	160,6	56,1	673,4	890,1
7,2	621,7	12,0	191,5	28,5	633,7	853,7
14,4	708,4	22,9	155,7	59,6	731,3	946,6
C.V. (%)	25,7	179,4	44,2	62,9	25,6	23,6
Linear	ns	*	ns	ns	ns	ns
Quadratic	ns	ns	ns	**	ns	ns
			Second year			
0	1.287,5	2,9	233,9	484,6	1.290,4	2.008,9
7,2	1.501,7	78,3	347,1	482,2	1.580,0	2.409,3
14,4	1.546,7	59,9	247,0	449,8	1.606,6	2.303,4
C.V. (%)	26,8	209,5	46,2	26,8	26,5	21,7
Linear	ns	ns	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns
			Third year			
0	933,2	1,1	169,8	523,2	934,2	1.627,2
7,2	1.141,9	34,5	196,5	594,2	1.176,4	1.967,0
14,4	1.151,3	31,0	189,0	696,1	1.182,3	2.067,4
C.V. (%)	19,5	162,7	48,9	23,3	20,3	18,4
Linear	*	*	ns	***	*	*
Quadratic	ns	ns	ns	ns	ns	ns
			Fourth year			
0	1.901,4	0,9	224,7	464,6	1.902,3	2.591,6
7,2	2.213,6	102,5	289,2	509,4	2.316,1	3.114,8
14,4	1.604,8	138,0	160,2	510,6	1.742,8	2.413,7
C.V. (%)	23,2	152,3	52,3	32,9	21,7	19,3
Linear	ns	**	ns	ns	ns	ns
Quadratic	**	ns	ns	ns	**	***

Data analyzed using orthogonal polynomial contrasts.
ns: not significant.
*, **, and ***: statistically different at a significance level of 10%, 5%, and 1%, respectively.

Table 3. Annual production of dry matter (DM; kg ha^{-1}) in each plant and morphological category selected for evaluation of the response of the soil surface to the application of different doses of phosphorus (P_2O_5 kg ha^{-1}).

Doses of phosphorus (kg of P_2O_5 ha^{-1})	Production of DM (kg ha^{-1})					
	Native grasses	Native leguminous plants	Undesirable plants	Dead material	Forage	Total DM
First year						
0	574,4	9,3	142,8	35,9	583,7	762,4
35	755,0	6,5	143,6	61,0	761,5	966,2
70	631,4	11,5	185,8	41,0	643,0	869,7
140	709,5	20,2	204,8	54,3	729,7	988,8
C.V. (%)	25,7	179,4	44,2	62,9	25,6	23,6
Linear	ns	ns	**	ns	ns	*
Quadratic	ns	ns	ns	ns	ns	ns
Second year						
0	1.190,5	13,0	302,2	475,1	1.203,5	1.980,8
35	1.518,3	9,7	252,0	420,0	1.393,1	2.011,9
70	1.615,9	41,4	266,0	506,2	1.657,3	2.429,5
140	1.456,6	124,0	283,8	487,5	1.580,6	2.351,9
C.V. (%)	26,8	209,5	46,2	26,8	26,5	21,7
Linear	ns	***	ns	ns	***	**
Quadratic	***	ns	ns	ns	*	ns
Third year						
0	990,7	9,3	192,8	604,6	1.000,0	1.797,3
35	1.084,1	8,8	162,9	575,0	1.092,9	1.830,7
70	1.076,9	27,7	204,0	660,9	1.104,7	1.969,6
140	1.150,1	42,9	180,7	577,4	1.193,0	1.951,2
C.V. (%)	19,5	162,7	48,9	23,3	20,3	18,4
Linear	*	**	ns	ns	**	ns
Quadratic	ns	ns	ns	ns	ns	ns
Fourth year						
0	1.847,9	27,3	238,6	343,3	1.875,2	2.457,0
35	1.905,3	52,7	211,8	512,9	1.958,0	2.682,7
70	1.796,6	119,8	205,1	519,9	1.916,4	2.641,4
140	2.076,5	122,1	243,4	603,5	2.232,8	3.045,5
C.V. (%)	23,2	152,3	52,3	32,9	21,7	19,3
Linear	ns	*	ns	***	*	***
Quadratic	ns	ns	ns	ns	ns	ns

Data analyzed by orthogonal polynomial contrasts
ns: not significant.
*, **, and ***: statistically different at a significance level of 10%, 5%, and 1%, respectively.

Native leguminous plants, represented primarily by white clover (*Trifolium repens* L.), had little contribution to forage production (the coefficient of variation was higher than 150%). Despite this, growth of this species increased linearly with increasing limestone doses in the first, third, and fourth year (Table 2), confirming the hypothesis that leguminous plants are more sensitive and responsive to the decrease in soil acidity (GATIBONI et al., 2000, 2003).

Although the production of undesirable plants is not influenced by limestone doses (Table 2), it is important to report the presence of a fern (*Pteridium aquilinum* L. Kuhn, a toxic plant considered to be an indicator of acidic soils (TOKARNIA et al., 2000) at the beginning of the study. Although it was unfeasible to make a detailed botanical description of undesirable plants, it was observed that *P. aquilinum* stopped growing after the application of limestone and management of the plots, probably due to decreased soil acidity (Table 1; Table 4).

Table 4. pH in water, exchangeable aluminum content (Al; $cmol_c$ kg^{-1}), and percentage of base saturation (V%) in different soil layers in response to surface application of different doses of limestone (t ha^{-1}) in a natural pasture. Average phosphorus levels of the third and fourth experimental year.

Limestone Dosages(t ha^{-1})	pH	Al	V%
		0-5 cm	
0	4,77	2,51	31,34
7,2	5,91	0,04	72,33
14,4	6,45	0,00	84,17
C.V. (%)	12,86	142,69	38,71
Linear	***	***	***
Quadratic	**	***	**
		5-10 cm	
0	4,65	3,87	21,29
7,2	5,06	2,20	30,06
14,4	5,44	1,38	50,85
C.V. (%)	8,19	50,11	45,25
Linear	***	***	***
Quadratic	ns	ns	*
		10-15 cm	
0	4,66	4,27	16,14
7,2	4,84	3,70	15,14
14,4	5,08	3,34	31,96
C.V. (%)	4,08	15,91	46,80
Linear	***	***	***
Quadratic	ns	ns	**
		15-20 cm	
0	4,60	4,53	12,46
7,2	4,78	4,14	11,59
14,4	5,08	3,85	26,48
C.V. (%)	6,14	16,00	54,96
Linear	***	**	**
Quadratic	ns	ns	Ns

Data analyzed by orthogonal polynomial contrasts.
ns: not significant.
*, ** and ***: significant at 10, 5, and 1% of probability, respectively.

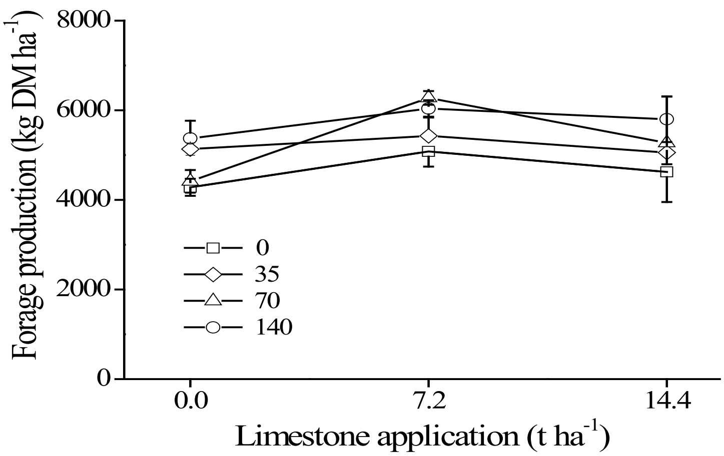
We observed a positive effect of phosphorus on the production of native grasses, with a quadratic and linear increase in growth in the second and third year, respectively (Table 3). The quadratic relationship between grass production and phosphorus levels in the second year can be explained by the chemical relationship between soil elements and pH. In the first year, the soil pH was low; therefore, part of the phosphorus was strongly adsorbed possibly in the form of precipitated iron phosphate and aluminum, and was unavailable to plants. However, the increase in pH decreased the solubility of aluminum and iron and increased soluble phosphorus concentrations (ERNANI et al., 2000), but also might have minimized the effect of high doses of phosphorus fertilizer in the second year possibly because these doses exceeded the capacity of utilization by grasses. Later, the increase of pH to 6.5 (Table 4, 0-5 cm layer) decreased the solubility of phosphorus due to the high calcium content (incorporated by liming) and formed precipitates of calcium phosphate (AKINREMI; CHO, 1991). Accordingly, the incorporation of high doses of phosphorus increased the availability of this nutrient in the soil and caused a linear increase in grass production in the third year with increasing doses of fertilizer used.

Native grasses had a greater abundance in the samples and were responsible for the effects of phosphorus on forage production, causing the discussion of the effect of phosphorus on the production of native grasses will be restricted to the same made for forage production. The production of native leguminous plants increased linearly in the second, third, and fourth year as phosphorus doses increased (Table 3). These results reinforce the high sensitivity of leguminous plants to phosphorus concentrations (FERREIRA et al., 2008), particularly in the present study, where this species group was represented primarily by white clover known for its high responsiveness to soil phosphorus content. The lack of effect of the fertilizer on the production of native leguminous plants during the first year of assessment is probably a result of high soil acidity observed in that year (Table 1), which affected the availability of soluble phosphorus (ERNANI et al., 2000). The effect of phosphorus doses on the production of undesirable plants was detected only in the first year of assessment, showing a linear increase (Table 3). This indicates that the lack of competition during protocol implementation in the first year of assessment increased the production of undesirable plants as the phosphorus doses increased. However, the growth of these plants was restricted even at higher doses of phosphorus after management practices were applied and forage production responded positively to treatment (second year).

Despite the lack of interaction between limestone and phosphorus, we observed a potentiation of their effects in isolation for the production of forage accumulated for four years (Figure 2), indicating that the limestone dose of 7.2 t ha^{-1}, associated with the phosphorus dose of 70 kg P_2O_5 ha^{-1}, is sufficient to maintain a high primary productivity over the years. Moreover, the application of higher doses of the phosphorus fertilizer and pH correction by limestone may not produce high yields owing to limitations in the level of nutrient absorption by the plants when these nutrients are readily available in the soil (ERNANI et al., 2000).

With regard to the effects of limestone on soil attributes, the pH in water, concentration of exchangeable aluminum, and base saturation (V%) were positively influenced by the applied doses (Table 4). Although the effects of surface liming practices at different soil depths are proportional to the dose, duration of liming, and rainfall (RHEINHEIMER et al., 2000; FIDALSKI; TORMENA, 2005), soil pH decreased linearly as the limestone doses increased in the third and fourth year, regardless of the soil layer assessed. These results are corroborated by those of Dabaan et al. (1997), where soil pH increased 8 years after the initiation of surface applications of limestone in natural pasturelands in the United States. In the Central Depression of Rio Grande do Sul, liming at a rate of 3.2 t ha^{-1} was sufficient to increase the pH between 5.7 and 5.9 and to eliminate the exchangeable aluminum content in the 0-10 cm layer after 141 months of application (TIECHER et al., 2014). Of note is the fact that pH decreased linearly even in deeper soil layers (15-20 cm) possibly because of the indirect effect of grazing, i.e., removal of the aerial parts of plants promote renewal of the root system, leading to the formation of microchannels that facilitate the penetration of limestone in the soil (FLORES et al., 2008; CARVALHO et al., 2011; MARTINS et al., 2014.).

Figure 2. Total forage production (kg DM ha^{-1}) during the four-year assessment period, according to limestone application (t ha^{-1}) and phosphorus doses (kg of P_2O_5 ha^{-1}) applied on the soil surface of a natural pastureland. Vertical bars correspond to the standard error of the mean.



The effect of different doses of phosphorus was limited to the surface layers of the soil (Table 5), highlighting the limited distribution of this nutrient in various soil profiles. Phosphorus concentration in the 0-5 and 5-10 cm layers increased linearly with the applied doses; however, this was not the case in the 10-15 cm and 15-20 cm layers. Similarly, Nunes et al. (2011) studied different crops in no-till systems and reported higher phosphorus concentrations in the 0-10 cm layers of the soil in the region of Planaltina, Federal District. We emphasize that even with marked effects of the dose of 140 kg P_2O_5 ha^{-1} in the 0-5 cm layer (Table 5), the phosphorus concentration reached only a concentration of 11.41 mg kg^{-1}, which is much lower than the environmentally critical limit for soils with 47% of clay (GATIBONI et al., 2014).

Table 5. Mean concentration of phosphorus (P; mg kg^{-1}) in different soil layers subjected to various doses of phosphate fertilizer (kg P_2O_5 ha^{-1}) applied on the soil surface of a natural pasture. Average limestone levels of the third and fourth experimental year.

Phosphorus dosages (kg of P_2O_5 ha^{-1})	P content (mg kg^{-1}) in the soil (Mehlich-1)			
	0-5 cm	5-10 cm	10-15 cm	15-20 cm
0	4,33	2,56	2,57	1,83
35	6,44	2,70	2,21	1,92
70	8,81	4,07	2,66	1,86
140	11,41	3,49	2,09	1,67
C.V. (%)	58,4	70,0	78,1	98,7
Linear	***	***	ns	ns
Quadratic	ns	***	ns	ns

Data analyzed by orthogonal polynomial contrasts.
ns: non-significant.
*, **, and ***: statistically different at a level of significance of 10%, 5%, and 1%, respectively.

Conclusions

Forage production on natural pasturelands with predominance of *Schizachyrium tenerum* was enhanced with the application of 25% of the recommended dose of limestone (7.2 t ha^{-1}) and with 50% of the recommended dose for phosphorus (70 kg P_2O_5 ha^{-1}).

The increase in the limestone dose directly influenced the chemical properties of the soil, and decreased the acidity and exchangeable aluminum and increased base saturation even in deeper layers (0-20 cm). The increase in phosphorus doses did not increase the mobility of this nutrient in the deeper layers of the soil (10-20 cm), and therefore its effects became restricted to a depth of up to 10 cm.

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