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Limestone and phosphorus application and forage production in natural pastures with sodseeding of cool-season species

Aplicação de calcário e fósforo e a produção de forragem em pastagem natural com introdução de espécies de estação fria

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Abstract

Natural pastures are important ecosystems that both contribute to biodiversity conservation and provide an important source of income, especially for cattle ranchers. While these pastures yield fairly low productivity, they can be improved by increasing soil fertility and introducing species with high productive potentials. In this sense, the purpose of this study was to evaluate the effects of applying limestone and phosphorus, as well as introducing cool-season species with a mixture of species dominated by *Schizachyrium tenerum* Nees, into a natural pasture in the Catarinense Plateau. The experiment was conducted from January 2010 to December 2013; the treatments consisted of superficial distribution of limestone in proportions of 3.6, 7.2, 11.0, and 14.4 t ha^{-1}, as well as distribution of phosphorus in the form of triple superphosphate in proportions of 35, 70, 105, and 140 kg of P_2O_5 ha^{-1}. In addition, cool-season species were overseeded. The experiment consisted of a randomized block design with subdivided plots and three replications. Limestone was applied to the main parcel, whereas phosphorus was applied to the subplots. There was no interaction between the levels of limestone and phosphorus. The application of 11.0 t ha^{-1} of limestone yielded the highest forage production, with 3,932.2 kg of dry matter (DM) ha^{-1} during the second year. Red clover was the species that best reacted to the additions, with levels of 7.2 and 11.0 t ha^{-1} over the 4 years. In addition, phosphorus provoked a positive response throughout the experiment. The highest forage production was observed during the second year, with an addition of 140 kg P_2O_5 ha^{-1} (4,419.4 kg DM ha^{-1}). Only one-eighth of the recommended amount of limestone (3.6 t ha^{-1}) allowed for the establishment and persistence of the legumes introduced into natural pastures. These additions, associated with increasing levels of phosphorus, yielded linear growth in the production of forage in natural pastures with a mixture of species dominated by *Schizachyrium tenerum* Nees.

Key words: Competition. Soil fertility. Native pastures.

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Resumo

As pastagens naturais representam um importante ecossistema, com contribuições tanto para manutenção da biodiversidade quanto para geração de renda aos produtores, principalmente na pecuária de corte. No entanto, os níveis de produtividade destas pastagens são relativamente baixos, e podem ser melhorados com incrementos em fertilidade do solo e introdução de espécies de elevado potencial produtivo. Assim, o objetivo deste estudo foi avaliar os efeitos da aplicação de níveis de calcário e fósforo, bem como da introdução de espécies de inverno em uma pastagem natural com predomínio de *Schizachyrium tenerum* Nees no Planalto Catarinense. O experimento foi conduzido de janeiro de 2010 a dezembro de 2013, e os tratamentos consistiram na distribuição superficial de calcário nas doses de 3,6; 7,2; 11,0 e 14,4 t ha^{-1}; distribuição de fósforo na forma de superfosfato triplo nas doses de 35; 70; 105 e 140 kg de P_2O_5 ha^{-1}; e a sobressemeadura de espécies de estação fria. O delineamento experimental foi em blocos ao acaso com parcelas subdivididas e três repetições. Os níveis de calcário foram distribuídos nas parcelas e os de fósforo nas subparcelas. Não houve interação entre os níveis de calcário e fosforo. A aplicação de 11,0 t ha^{-1} de calcário propocionou a maior produção de forragem, de 3.932,2 kg MS ha^{-1}, no 2º ano. O trevo-vermelho foi a espécie que melhor respondeu ao corretivo, nos níveis de 7,2 a 11,0 t ha^{-1} durante os 4 anos. O fósforo proporcionou resposta positiva durante todo período experimental. A máxima produção de forragem ocorreu no 2º ano para a dose de 140 kg P_2O_5 ha^{-1} (4.419,4 kg MS ha^{-1}). Apenas 1/8 da recomendação de calcário (3,6 t ha^{-1}) permite o estabelecimento e a persistência de leguminosas introduzidas em pastagem natural, dose esta que associada à níveis crescentes de fosforo proporcionam aumentos lineares na produção de forragem em pastagem natural com predomínio de *Schizachyrium tenerum* Nees.

Palavras-chave: Competição. Fertilidade do solo. Campo nativo.

Introduction

It is estimated that 919.6 thousand hectares in the Brazilian State of Santa Catarina (SC) are occupied by natural pastures (ARAÚJO et al., 2007). A large part of these are found in the Catarinense Plateau. According to data from the Brazilian Agricultural Census (IBGE, 2006), 400 thousand hectares were lost in the last 15 years due to substitution with agricultural crops and, mainly, afforestation (BOLDRINI, 2009; CÓRDOVA et al., 2012). Despite adverse conditions and limitations, such as soils with high acidity and low natural fertility, high contents of aluminum (Al), rugged relief, stoniness, and rocky outcrops, natural pastures continue to be the main source of food for livestock in the region.

Pasture production is higher during the hot seasons of the year, given that they primarily harbor various C4 Gramineae species. Production systems based on natural pastures are usually extensive, with stocking rates of approximately 0.3 to 0.4 animal units (AU) ha^{-1}. These numbers are usually defined by the forage supply from fall and winter, the seasons with the smallest growth. Given these conditions, it is difficult to produce more than 60 to 70 kg ha^{-1} $year^{-1}$ of live weight (CARVALHO et al., 2006), which is very low when compared to the production potential of natural pastures in the South Region of Brazil (MARASCHIN, 2009). Therefore, it is of critical importance to increase the productive capacity of these pastures, specifically with respect to the competitiveness of livestock.

To achieve this, it is necessary to use techniques that preserve the ecosystem, provide competent productivity indices, and ensure the sustainability of the productive systems (CASTILHOS et al., 2011). In this sense, the introduction of cool-season species into natural pastures is an interesting option for boosting forage production and quality and mitigating the effects of seasonality (BARTHOLOMEW; WILLIAMS, 2010). When enhancing native pastures (ENP), the use of forage legumes is crucial for increasing forage production and quality, as well as the nitrogen (N) fixation capacity of the soil. This benefits other forage species in the field and improves soil fertility (PRESTES; JACQUES, 2002). As such, the purpose of this study was to evaluate forage production and the endurance of temperate forage species overseeded in natural pastures with a mixture dominated by *Schizachyrium tenerum* Nees treated with limestone and phosphorus (P).

Materials and Methods

The experiment was conducted in Lages, SC, from January 2010 to December 2013, in a natural pasture with combined species dominated by slender little bluestem (*Schizachyrium tenerum* Nees). The climate has a Köppen classification of Cfb, whereas the soil is classified as Nitosol Bruno (EMBRAPA, 2006). The experimental area is located at latitude: 28°01′30.79″ S, longitude: 50°25′03.13″ W, and at an altitude of 1,140 m.

The treatments consisted of superficial application of dolomitic limestone with a total relative neutralizing power (TRNP) of 60%. This was added in proportions of 12.5%, 25.0%, 37.5%, and 50.0% of the recommended amount for conventional crops (CQFS-RS/SC, 2004), which is equivalent to 3.6, 7.2, 10.8, and 14.4 t ha^{-1}. P was also applied in the form of triple superphosphate, in proportions of 25.0%, 50.0%, 75.0%, and 100.0% of the recommended amount for the combined cultivation of Gramineae species and cool-season legumes (CQFS-RS/SC, 2004), which is equivalent to 35.0, 70.0, 105.0, and 140 kg of P_2O_5 ha^{-1}.

The following cool-season species were introduced: white clover (*Trifolium repens* L.) ‘Zapicán’ (3 kg ha^{-1}), red clover (*Trifolium pratense* L.) ‘Quiniquelli’ (5 kg ha^{-1}), bird’s-foot trefoil (*Lotus corniculatus* L.) ‘São Gabriel’ (5 kg ha^{-1}), Italian ryegrass (*Lolium multiflorum* Lam.) ‘Comum’ (30 kg ha^{-1}), tall fescue (*Festuca arundinacea* Schreb.) ‘El Palenque’ (15 kg ha^{-1}), and velvet grass (*Holcus lanatus* L.) ‘La Magnolia’ (6 kg ha^{-1}). These species were overseeded on July 14, 2010, followed by superficial harrowing.

The experiment had a randomized complete block design with subdivided plots and three replications. The subplots were 6 × 3 m with borders of 1 m and a useful area of 4 m². The limestone and P were applied to the main parcel and the subplots, respectively, and were defined based on a previous analysis of the soil. This analysis was completed using 20 samples that were collected in the experimental area and combined into a composite sample (Table 1).

Table 1. Soil chemical attributes before limestone, phosphorus, and nitrogen were applied. Lages, SC.

Depth	Clay	pH-H_2O	Index	P	K	Organic Matter	Al	Ca	Mg	Base Saturation
(cm)	(%)	(1:1)	SMP*	(mg/dm³)		(%)	(cmol$_c$/dm³)			V%
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

*Shoemaker, Mac lean and Pratt Method.

The limestone and P were applied on February 9, 2010 and July 7, 2010, respectively. Samples from every subplot were collected on May 3, 2012 and April 25, 2013, using an auger with a diameter of 10 cm.

Maintenance fertilization was performed at the end of every warm season using amounts equivalent to 30% of the base P fertilization (CQFS-RS/SC, 2004). Forage production was obtained by using a chainsaw with a cutting range of 1 m to cut at a height of 8.0 cm from the ground. All cut green material was weighed, subsampled, and weighed again. The subsamples were botanically separated as native Gramineae species and legumes, each of the introduced species, undesirable plants, and dead material. Each of these was kept in an oven at 60°C with forced air ventilation until constant weight. The produced material from each cutting session was added up to obtain the total annual production as follows: two cutting sessions in the first year (November 30, 2010 and January 11, 2011), four cutting sessions in the second year (April 5, 2011, June 15, 2011, October 19, 2011, and January 04, 2012), two cutting sessions in the third year (March 29, 2012 and December 6, 2012), and two cutting sessions in the fourth year (April 12, 2013 and November 05, 2013). Cutting was dependent upon an average grazing height of 20 cm before cutting, independent of the treatments.

The experiment continued despite damage to production due to senescence, death of plant components, long periods between cutting sessions, and production seasonality. To evaluate the establishment (initial plant population) of the introduced species, plants within frames with sides of 20 cm were counted at three sample points within the useful area of each subplot on November 17, 2010. The same process was performed on January 22, 2014 to evaluate the persistence (final plant population) of the introduced species. The results obtained were submitted for analysis of variance. The effects of the treatments were analyzed using orthogonal polynomial contrasts (linear and quadratic) and a significance level of 10% was adopted to compare differences among treatments.

Results and Discussion

There was no interaction between the limestone and P additions in any of the variables studied. Production was lower than expected (Tables 2 and 3). This could be attributed to the 8 cm cutting height, resulting in a large part of green material being left out. This effect may have also resulted from the long intervals between the cutting sessions and the variable number of times that they occurred. Forage produced and senesced between cuts was not taken into account.

In general, there was an increase in forage production when applying limestone and P, except during the third year, when production was affected by low rainfall, as shown in Figure 1. In addition, there were differences in the production of native Gramineae species as a function of added limestone over the first year (Table 2). This response may have been the result of the direct contribution of the biological N fixation promoted by the legumes introduced. This is assuming that the limestone had not yet counteracted the soil acidity.

The boost in forage production during the initial stage of the experimental period, especially in the second year, was due to the increase in mass of cool-season species. These species did not contribute as much over the following years, most likely because of competition with the greater quantity of native Gramineae species (Table 2). This indicates an improvement in soil fertility (PRESTES et al., 2016).

In a similar study carried out in the central depression of the Brazilian State of Rio Grande do Sul (RS), the limestone did not affect forage production during ENP. This was also the case for the introduction of white clover, with or without cover and N-P-K maintenance fertilization (CASTILHOS; JACQUES, 2000). There was a quadratic effect in production during the first two years, with higher values in treatments with an addition of 11.0 t ha^{-1}. However, in the third year, the growth was linear with limestone content (Table 2). In addition, there were long droughts (Figure 1), as well as an increase in the production of native Gramineae species and a decrease in the production of the introduced species, demonstrating the higher tolerance of native species to water stress (NABINGER, 2006).

Table 2. Annual dry matter (DM) production (kg ha^{-1}) of each of the components (Ng: native Gramineae; Nl: native legumes; Wc: white clover; Rc: red clover; Bt: bird's-foot trefoil; Ir: Italian ryegrass; Tf: tall fescue; Vg: velvet grass; Up: undesired plants; Dm: dead material; Fr: forage and total DM) of a natural pasture with introduced cool-season species, in response to the addition of different amounts of limestone (tons ha^{-1}). Lages, SC.

Limestone	DM production (kg ha^{-1})											
(t ha^{-1})	Ng	Nl	Wc	Rc	Bt	Ir	Tf	Vg	Up	Dm	Fr	Total DM
	First Year											
3.6	716.4	0.0	113.4	513.5	81.5	84.6	7.2	23.2	260.6	190.0	1,539.8	1,990.3
7.2	788.7	0.0	71.0	655.9	84.2	74.0	3.3	37.6	211.5	188.0	1,714.6	2,114.0
11.0	843.5	0.0	102.9	712.5	106.3	83.5	4.6	56.3	207.8	271.9	1,909.6	2,389.3
14.4	665.4	0.0	72.1	642.7	121.0	70.5	2.4	16.7	311.3	199.8	1,590.8	2,101.9
CV (%)	25.5	-	83.5	33.9	40.5	44.2	133.6	114.0	84.3	40.2	20.1	19.3
Linear	ns	-	ns	ns	**	ns	**	ns	ns	ns	ns	ns
Quadratic	*	-	ns	*	ns	ns	ns	*	ns	ns	**	*
	Second Year											
3.6	746.0	0.0	52.5	2,391.9	181.2	7.1	0.0	309.7	92.1	763.1	3,688.5	4,543.7
7.2	679.7	0.0	35.6	3,068.4	165.6	10.9	0.0	367.5	31.3	836.6	4,327.7	5,195.7
11.0	529.7	0.2	59.7	2,729.0	188.7	19.3	0.0	405.6	136.1	705.4	3,932.2	4,773.7
14.4	577.1	0.0	37.8	2,451.1	233.3	9.0	0.3	353.0	114.1	689.0	3,661.7	4,464.8
CV (%)	28.5	692.8	63.0	18.5	39.6	98.0	692.8	69.6	138.4	24.7	15.9	15.6
Linear	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Quadratic	ns	ns	ns	***	ns	**	ns	ns	ns	ns	***	**
	Third Year											
3.6	879.7	0.0	0.4	226.1	43.8	0.0	0.0	235.4	137.8	376.2	1,385.4	1,899.4
7.2	679.7	0.0	0.0	345.5	21.6	0.0	0.0	238.7	116.0	445.6	1,285.5	1,847.1
11.0	1,044.8	0.0	0.1	292.9	21.7	0.0	0.0	254.1	123.4	261.1	1,613.5	1,998.1
14.4	997.4	0.0	0.0	297.1	31.4	0.0	0.0	155.1	67.2	342.7	1,481.0	1,890.9
CV (%)	26.4	-	569.7	33.0	63.2	-	-	92.1	73.2	46.1	20.2	17.3
Linear	***	-	ns	ns	**	-	-	ns	ns	ns	*	ns
Quadratic	ns	-	ns	*	***	-	-	ns	ns	ns	ns	ns
	Fourth Year											
3.6	2,252.0	0.0	27.3	279.4	29.5	0.0	0.0	558.7	150.5	664.2	3,146.8	3,961.5
7.2	1,736.9	0.0	42.0	341.8	27.6	0.0	0.8	582.9	109.0	569.8	2,732.1	3,410.8
11.0	2,009.1	0.0	56.2	402.4	34.0	0.0	0.0	497.2	168.9	554.4	2,998.9	3,722.3
14.4	2,074.2	0.0	39.0	305.5	36.7	0.0	29.3	316.7	150.5	678.3	2,801.3	3,630.1
CV (%)	23.2	-	138.4	38.3	97.8	-	309.9	99.6	69.7	29.9	18.0	17.8
Linear	ns	-	ns	ns	ns	-	**	ns	ns	ns	ns	ns
Quadratic	*	-	ns	**	ns	-	*	ns	ns	*	ns	ns

Data was analyzed using orthogonal polynomial contrasts.
ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

The white clover presented low production (Tables 2 and 3). This could be the result of its slow establishment and the concurrent competition, which kept it from achieving its productive potential (VIDOR et al., 1997). On the other hand, the fact that it is a species of rather prostrate growth could have made it less likely to be cut, which caused its mass to be underestimated in relation to the other species.

Table 3. Annual DM production (kg ha^{-1}) for each of the components (Ng: native Gramineae; Nl: native legumes; Wc: white clover; Rc: red clover; Bt: bird's-foot trefoil; Ir: Italian ryegrass; Tf: tall fescue; Vg: velvet grass; Up: undesired plants; Dm: dead material; Fr: forage and total DM) of a natural pasture with introduced cool-season species, in response to the addition of different amounts of phosphorus (kg of P_2O_5 ha^{-1}). Lages, SC.

Phosphorus (kg of P_2O_5 ha^{-1})	DM production (kg ha^{-1})											
	Ng	Nl	Wc	Rc	Bt	Ir	Tf	Vg	Up	Dm	Fr	Total DM
						First Year						
35	764.3	0.0	56.1	480.6	86.5	85.5	4.6	34.8	246.7	178.4	1,512.4	1,937.5
70	720.6	0.0	62.5	591.5	97.2	85.1	4.7	40.3	233.3	245.9	1,601.9	2,081.0
105	794.0	0.0	103.1	676.1	104.8	60.0	4.4	12.5	158.2	195.7	1,755.0	2,108.9
140	735.1	0.0	137.8	776.3	104.3	82.0	3.8	46.1	353.0	229.7	1,885.4	2,468.1
CV (%)	25.5	-	83.5	33.9	40.5	44.2	133.6	114.0	84.3	40.2	20.1	19.3
Linear	ns	-	***	***	ns	ns	ns	ns	ns	ns	***	***
Quadratic	ns	-	ns	ns	ns	ns	ns	*	*	ns	ns	ns
						Second Year						
35	661.2	0.2	35.3	2,318.2	143.5	7.7	0.3	263.2	66.4	643.2	3,429.7	4,139.3
70	637.8	0.0	48.7	2,596.9	219.8	14.5	0.0	343.2	142.6	801.6	3,861.0	4,805.2
105	627.8	0.0	50.4	2,768.8	193.3	10.1	0.0	249.7	57.5	725.8	3,900.0	4,683.3
140	605.6	0.0	51.3	2,956.6	212.1	14.0	0.0	579.8	107.1	823.5	4,419.4	5,350.1
CV (%)	28.5	692.8	63.0	18.5	39.6	98.0	692.8	69.6	138.4	24.7	15.9	15.6
Linear	ns	ns	ns	***	*	ns	ns	***	ns	**	***	***
Quadratic	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
						Third Year						
35	888.2	0.0	0.0	285.7	25.3	0.0	0.0	103.0	106.8	312.0	1,302.2	1,721.0
70	927.1	0.0	0.0	305.6	35.5	0.0	0.0	253.6	125.0	326.8	1,521.7	1,973.6
105	944.0	0.0	0.4	283.4	24.1	0.0	0.0	160.1	81.6	344.2	1,412.1	1,837.8
140	842.5	0.0	0.1	286.9	33.5	0.0	0.0	366.6	131.1	442.5	1,529.6	2,103.1
CV (%)	26.4	-	569.7	33.0	63.2	-	-	92.1	73.2	46.1	20.2	17.3
Linear	***	-	ns	ns	ns	-	-	***	ns	**	ns	**
Quadratic	ns	-	ns	ns	ns	-	-	ns	ns	ns	ns	ns
						Fourth Year						
35	2,012.4	0.0	48.1	294.5	43.5	0.0	6.2	366.2	136.1	506.8	2,771.0	3,413.9
70	2,129.3	0.0	56.7	287.6	27.4	0.0	8.1	409.6	185.6	617.7	2,918.7	3,722.0
105	2,036.5	0.0	26.2	355.4	29.8	0.0	6.6	304.5	130.3	578.3	2,759.0	3,467.6
140	1,893.9	0.0	33.5	391.4	27.0	0.0	9.2	875.3	127.0	763.9	3,230.4	4,121.4

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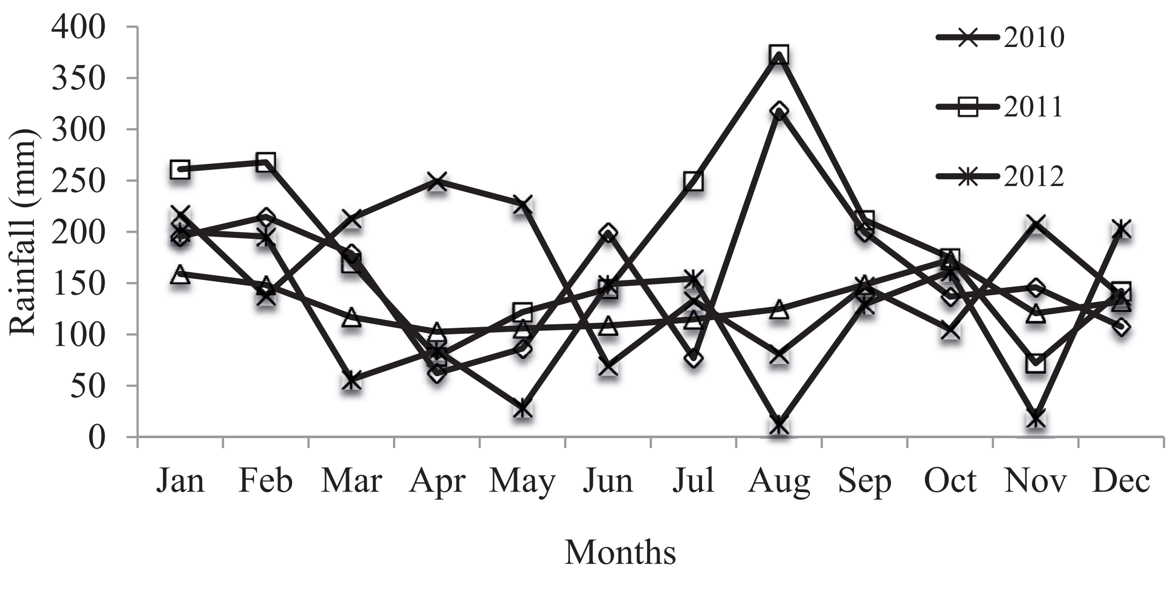
CV (%)	23.2	-	138.4	38.3	97.8	-	309.9	99.6	69.7	29.9	18.0	17.8
Linear	ns	-	ns	**	ns	-	ns	**	ns	***	*	***
Quadratic	ns	-	ns	ns	ns	-	ns	*	ns	ns	ns	ns

Data was analyzed using orthogonal polynomial contrasts.
ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

The highest production values for red clover were between 7.2 and 11.0 t ha^{-1} (Table 2), distinguishing it from the other introduced species. The bird's-foot trefoil had its highest production during the second year, with a linear growth with respect to added limestone in the first and third years (Table 2). Jacques and Nabinger (2000) demonstrated that only 3.0 t of limestone ha^{-1}, with a TRNP of 104% in superficial application, were necessary to succeed in ENP; this was observed specifically for white and red clover and Italian ryegrass in soil demanding 29.7 t of limestone ha^{-1}. Meanwhile, the production of velvet grass increased up until the end of the experiment (Table 2). This was largely because of its ability to persist and high capacity to naturally recover (VIDOR et al., 1997).

Figure 1. Monthly accumulated rainfall over the course of the experiment. Data collected by Epagri - Meteorological Station at the Lages Experimental Station, SC.

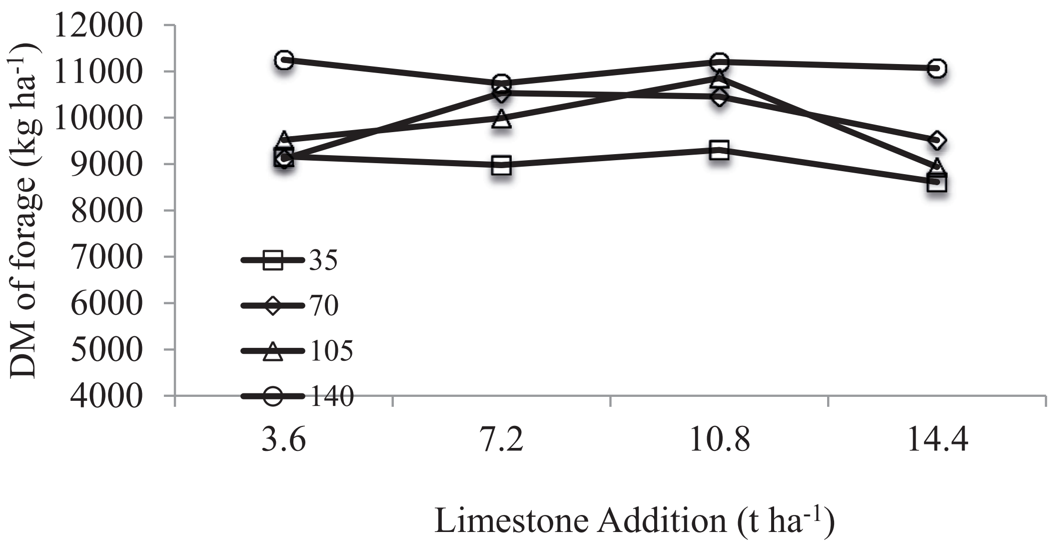


Forage yielded the highest production values for intermediate levels of limestone and P (Table 2 and 3). In this sense, the use of 25.0 to 37.5% of the official amount recommended (CQFS-RS/SC, 2004) displayed significant positive effects for ENP. Meanwhile, the native Gramineae species were indifferent to P (Table 3), demonstrating that P has a greater impact on legumes than on Gramineae species (FERREIRA et al., 2008). The only difference was in the third year, where their response was linear with respect to P concentration.

Red clover showed linear growth with respect to P concentration, with a peak in the second year (Table 3); the third year was an exception. As such, this species stood out from the others. Meanwhile, velvet grass exhibited stable growth over the 4 years, thereby demonstrating sensitivity to P additions (Table 3).

Even though there was no interaction between the treatments with respect to forage production, their effects were amplified when applied jointly, especially when using intermediate amounts (Figure 2). A 12-year ENP study completed in Santa Maria, RS gave the highest production values for Italian ryegrass and clover (*Trifolium vesiculosum* Savi.) as a result of combining P and added limestone (TIECHER et al., 2014).

Figure 2. Total DM production (kg ha^{-1}) accumulated over the four years of the experiment as a function of added limestone (t ha^{-1}) and additions of phosphorus of 35, 70, 105, and 140 kg of P_2O_5 ha^{-1} that were superficially applied to natural pasture with introduced cool-season species. Lages, SC. Vertical bars indicate standard error.



The population of introduced plants drastically decreased when comparing the initial count (establishment) to the final count (persistence) (Tables 4 and 5). The white clover, bird's-foot trefoil, and Italian ryegrass were indifferent to added limestone (Table 4). Furthermore, the establishment of red clover was notable, with 593 plants m^{-2} using a limestone addition of 7.2 t ha^{-1}; higher amounts resulted in a reduction in population (Table 4). Overall, this was the species that best persisted in the area, which indicates that higher amounts of limestone are not necessary to generate an acceptable population of red clover (Table 4).

Table 4. Persistence evaluation of cool-season species introduced into natural pasture, with a plant count performed on November 17, 2010 (initial plant population) and January 22, 2014 (final plant population), as a function of various additions of limestone (t ha^{-1}). Lages, SC.

Limestone Addition	Number of Plants m^{-2}					
(tons ha^{-1})	White clover	Red clover	Bird's-foot trefoil	Italian ryegrass	Tall fescue	Velvet grass
			Initial plant population			
3.6	141.7	153.5	184.7	284.7	22.2	87.5
7.2	172.9	593.1	170.1	160.4	22.2	54.9
11.0	170.8	152.8	194.4	296.5	56.2	136.1
14.4	94.4	131.2	122.9	209.7	49.3	109.0
CV (%)	62.9	83.5	47.2	44.6	65.9	65.5
Linear	ns	***	ns	ns	***	**
Quadratic	ns	***	ns	ns	ns	ns
			Final plant population			
3.6	22.9	135.4	52.1	0.0	8.3	60.4
7.2	13.9	78.5	41.0	0.7	0.7	59.0
11.0	11.1	58.3	26.4	0.0	1.4	34.0
14.4	32.6	50.7	36.1	0.0	16.7	43.8
CV (%)	120.1	49.9	72.8	692.8	149.6	60.0
Linear	ns	***	ns	ns	**	ns
Quadratic	ns	**	ns	ns	***	ns

Data was analyzed using orthogonal polynomial contrasts.
ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

With respect to P (Table 5) and the initial plant population, only the red clover and tall fescue differed statistically, presenting a linear and quadratic effect, respectively. There was a general decrease in plant population in the final count, except for with white and red clover, which showed linear growth (Table 5). Meanwhile, the bird's-foot trefoil was indifferent to P in both evaluations (Table 5). This is likely due to the low demand of the plant for soil fertility (VIDOR et al., 1997).

An alkaline front, formed by superficial liming, slowly grew, reaching higher rates as additions were elevated and yielding higher concentrated effects at 10 cm of depth (KAMINSKI et al., 2005; PANDOLFO et al., 2013). In addition, pH varied significantly and Al content showed an inverse relationship to limestone growth from 0 to 5 cm. Base saturations were also elevated (Table 6). Similarly, a study completed in Australia showed that the effects of superficial liming were limited to a depth of 5 cm (SMITH et al., 1994). It is worth noting that a limestone addition of 3.6 t ha^{-1}, which represents one-eighth of the recommended amount (CQFS-RS/SC, 2004), decreased the initial content of 2.81 (Table 1) to 0.67 cmol$_c$ kg^{-1} of Al (Table 6). Furthermore, an addition of 14.4 t ha^{-1} lowered Al content to almost zero. Similarly, soil P content varied the most at a depth of 0 to 5 cm, reaching its highest concentration when using an addition of 140 kg of P_2O_5 ha^{-1} (Table 7).

Table 5. Persistence evaluation of cool-season species introduced into natural pasture, with a plant count performed on November 17, 2010 (initial plant population) and January 22, 2014 (final plant population), as a function of various phosphorus additions (kg of P_2O_5 ha^{-1}). Lages, SC.

Phosphorus Additions (kg of P_2O_5 ha^{-1})	Number of Plants m^{-2}					
	White clover	Red clover	Bird's-foot trefoil	Italian ryegrass	Tall fescue	Velvet grass
	Initial plant population					
35	162.0	298.6	184.7	269.4	44.4	102.1
70	104.2	231.3	141.7	252.1	29.9	109.7
105	191.7	293.8	184.0	202.8	29.2	81.3
140	121.5	206.9	161.8	227.1	46.5	94.5
CV (%)	62.9	83.5	47.2	44.6	65.9	65.5
Linear	ns	**	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	**	ns
	Final plant population					
35	27.8	91.7	40.3	0.0	7.6	43.1
70	13.2	79.9	41.0	0.0	4.2	50.7
105	16.7	75.0	43.8	0.7	9.7	47.9
140	2.3	76.4	30.6	0.0	5.6	55.6
CV (%)	120.1	49.9	72.8	692.8	149.6	60.0
Linear	**	*	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns

Data was analyzed using orthogonal polynomial contrasts.
ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

In successive crops of soybean and corn, most P was superficially applied by hand; in this case, the highest P concentrations were observed at depths of 0 to 2.5 cm (BARBOSA et al., 2015). Such a high concentration in the 0 to 5 cm layer, even when increasing the amount of P additions, was due to the low movement of this nutrient caused by its strong fixation to the soil (GATIBONI et al., 2000). In addition, the legumes making use of P did not allow the nutrient to descend further. In Campos de Cima da Serra, RS, Heringer et al. (2002) demonstrated that ENP performed 7 and 24 years ago increased the levels of calcium (Ca), magnesium (Mg), P, base saturation (V%), and pH, even in deeper layers of soil (HERINGER et al., 2002). Since the application of limestone and P is subsurface in ENP, the use of intermediate amounts is preferred over the official recommendations. In addition, this process should be carried out at suitable periods until reaching the desired levels of soil fertility.

Table 6. Average values from the third and fourth year for pH in water, exchangeable aluminum content (Al) ($cmol_c$ kg^{-1}), and base saturation percentage (V%) at different soil depths, in response to added limestone (tons ha^{-1}) in natural pasture with introduced cool-season species. All measurements are for average phosphorus values. Lages, SC.

Limestone Additions (tons ha^{-1})	pH	Al	V%
		0-5 cm	
3.6	5.35	0.67	50.06
7.2	5.37	0.46	56.38
11.0	5.68	0.10	66.96
14.4	6.04	0.03	74.56
CV (%)	6.21	147.68	18.97
Linear	***	***	***
Quadratic	***	ns	ns
		5-10 cm	
3.6	4.74	3.33	19.54
7.2	4.63	3.17	14.61
11.0	4.76	2.70	21.52
14.4	4.85	2.88	21.33
CV (%)	2.93	23.27	32.86
Linear	**	**	ns
Quadratic	**	ns	ns
		10-15 cm	
3.6	4.61	4.58	10.82
7.2	4.45	4.67	7.99
11.0	4.61	4.24	9.90
14.4	4.61	4.33	9.28
CV (%)	2.66	14.18	34.81
Linear	ns	ns	ns
Quadratic	*	ns	ns
		15-20 cm	
3.6	4.60	5.11	7.53
7.2	4.41	5.14	5.09
11.0	4.60	4.82	5.52
14.4	4.62	5.23	6.26
CV (%)	2.95	10.58	40.00
Linear	ns	ns	ns
Quadratic	**	ns	ns

Data was analyzed using orthogonal polynomial contrasts; ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

Table 7. Phosphorus content at various soil depths in response to the application of different amounts of this element (kg of P_2O_5 ha^{-1}) to natural pasture with introduced cool-season species. All measurements are for average limestone values. Lages, SC.

Phosphorus Additions	P content (mg kg^{-1}) in soil (Mehlich-1)			
(kg of P_2O_5 ha^{-1})	0-5 cm	5-10 cm	10-15 cm	15-20 cm
35	7.05	3.99	2.69	1.93
70	10.56	4.05	2.28	1.65
105	11.64	4.15	2.48	2.15
140	12.08	4.15	2.45	1.71
CV (%)	35.98	43.53	64.72	46.73
Linear	***	ns	ns	ns
Quadratic	**	ns	ns	ns

Data was analyzed using orthogonal polynomial contrasts; ns: not significant.
*, **, and ***: significant at 10%, 5%, and 1%, respectively.

Conclusions

The addition of one-eighth of the recommended amount of limestone, equivalent to 3.6 t ha^{-1}, allowed for the establishment and persistence of legumes introduced into a natural pasture with a mixture of species dominated by *Schizachyrium tenerum* Nees.

The joint application of one-eighth of the recommended limestone addition (3.6 t ha^{-1}), with increasing additions of P, amplified forage production in native pastures. This was the result of, mainly, the beneficial effect that P had over the introduced forage legumes.

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