

LIMING AND FERTILIZATION TO RESTORE DEGRADED *Brachiaria decumbens* PASTURES GROWN ON AN ENTISOL

Patrícia Perondi Anção Oliveira^{1,5}; Antonio Enedi Boaretto²; Paulo Cesar Ocheuze Trivelin^{1*}; Wladecir Salles de Oliveira^{3,5}; Moacyr Corsi⁴

¹Lab. de Isótopos Estáveis - USP/CENA.

²Lab. de Nutrição Mineral de Plantas - USP/CENA, C.P. 96 - CEP: 13400-970 - Piracicaba, SP.

³Lab. de Biologia Molecular e Celular - USP/CENA.

⁴Depto. de Zootecnia - USP/ESALQ, C.P. 09 - CEP: 13418-900 - Piracicaba, SP.

⁵FAPESP Fellow.

*Corresponding author <pcotrive@cena.usp.br>

ABSTRACT: The reconstitution of soil fertility is essential in the process of pasture restoring, liming being the first action to be taken in this direction. The liming recommendation for pastures needs more technical information as the application method and rate. A field experiment was carried out to evaluate the liming and fertilization practices to restore a degraded *Brachiaria decumbens* pasture. The following factors were studied: liming method (incorporated in soil by disking or not); level of base saturation (40, 50 or 80%) and lime type (55, 70 or 90 of ECC). Liming and fertilization (NPK and micronutrients) increased both the forage yield and its root system, these being more evident in the second year, even using the same rates of lime and fertilizer used during the first year. After two years the levels of base saturation aimed for the 0 to 0.20 m soil layer were not achieved, neither was the neutralization of the Al. The disking impaired the development of the root system of *B. decumbens* and promoted the decrease of soil organic matter. The lime with the lowest ECC increased root growth and led to higher concentrations of Ca and Mg in the soil. Studies in other conditions are necessary to define liming requirements in established and degraded pastures.

Key words: ECC, lime, restoration, base saturation, acid soils

CALAGEM E ADUBAÇÃO NA RECUPERAÇÃO DE PASTAGEM DEGRADADA DE *Brachiaria decumbens* EM NEOSSOLO QUARTZARÊNICO

RESUMO: Na recuperação de pastagens é fundamental a reconstrução da fertilidade do solo, sendo a calagem a primeira ação nessa direção. A recomendação de calagem para pastagens necessita de maiores subsídios técnicos, como a forma de aplicação e a dose e o tipo de calcário a ser empregado. Um experimento de campo foi instalado para avaliar a calagem e a adubação como práticas para a recuperação de pastagens de *Brachiaria decumbens* degradadas. Os seguintes fatores foram estudados: a forma de aplicação do calcário (incorporado no solo com gradagem ou não incorporado), os níveis de saturação por bases de 40, 60 ou 80% e tipos de calcário (PRNT de 55, 70 ou 90). A calagem e a fertilização (NPK e micronutrientes) aumentaram as produções da forragem e do seu sistema radicular, sendo os efeitos mais acentuados no segundo ano, apesar do uso de mesmas doses de corretivos e fertilizantes do primeiro ano. Após dois anos não se conseguiu atingir os níveis de saturação por bases pretendidos na camada de 0 - 0,20 m, bem como a neutralização do Al. A gradagem prejudicou o desenvolvimento do sistema radicular da forrageira e promoveu queda nos teores da matéria orgânica no solo. O calcário de PRNT mais baixo aumentou a produção de raízes e proporcionou as maiores concentrações de Ca e Mg no solo. Estudos em outras condições são necessários para se aprimorar a recomendação de calagem para pastagens estabelecidas e degradadas.

Palavras-chave: PRNT, calcário, restauração, saturação por bases, solos ácidos

INTRODUCTION

Degraded *Brachiaria* pastures are supposed to cover 30 million ha of Brazil's territory (Zimmer et al., 1994). Restoring those areas may become strategic, both, for the economical importance of the agro-systems, and for their preservation, since degradation is very associated to erosion, causing sediment deposition in rivers and lakes. Adequate physiological management of forages and soil fertility improvement are necessary practices to be performed to restore degraded pastures.

Liming and fertilization are important actions to improve soil fertility, although liming of pastures being a controversial issue and, therefore, additional research is needed to clarify some liming aspects on established pastures.

Werner et al. (1996) recommended a soil base saturation (BS) of 70% for planting or 60% for pasture maintenance, for *Pennisetum purpureum*, *Panicum maximum*, *Cynodon dactylon*, *Digitaria decumbens*, *Hyparrhenia rufa* and *Chloris gayana* pastures; 60% of BS for the formation period or 50% for the maintenance

of *Brachiaria brizantha*, *Andropogon gayanus* e *Cynodon plectostachyus* pastures; and 40% of BS for the formation period or maintenance of *Brachiaria decumbens*, *Brachiaria humidicola*, *Melinis minutiflora*, *Paspalum notatum* and *Setaria anceps* pastures.

Maximum yield for *Brachiaria brizantha* and *Panicum maximum*, growing in greenhouse conditions, were obtained under soil BS of 43% and 47%, respectively (Premazzi, 1991). In the first year after lime application, there was no effect on *Panicum maximum* 'Tobiatã' pasture yield, despite of the soil BS value of 31% and that lime amounts were applied in order to reach 60% or 80% (Luz et al., 1998), although these authors are not sure if the aimed BS levels were reached or not.

Effects of liming and fertilization of degraded pastures for restoration seem to be more evident when they are monitored for many years (Couto et al., 1985; Macedo, 1985; Sanzonowicz et al., 1987; Carvalho et al., 1992; Paulino et al., 1994). Macedo (1985) observed an increase from 14 to 38% in forage yield over a five year period, for *Festuca* pasture mixed with legumes, although liming was not effective in the first year. Sanzonowicz et al. (1987) observed an increase in *Brachiaria decumbens* forage yield after ten years of liming. Positive response of *Brachiaria brizantha* pasture was observed for lime rates until 2.0 Mg ha⁻¹, as well increases of the effectiveness of phosphate fertilization (Paulino et al., 1994). Similar findings were obtained by Couto et al. (1985).

Disking for lime incorporation in soil cultivated with pastures is a controversial practice (Arruda et al., 1987; Soares Filho et al., 1992 and Luz et al., 1998). A slight increase on forage yield (130 kg ha⁻¹) was observed when lime was incorporated into the soil of a degraded *Panicum* pasture by disking (Luz et al., 1998). On the other hand, disking decreased the dry aboveground matter of *Brachiaria decumbens* pasture (Soares Filho et al., 1992).

There are several reports in the literature showing that anions (especially chloride, sulfate and nitrate) are responsible for increasing Ca and Mg leaching (Lopes, 1984; Souza e Ritchey, 1986; Raji, 1991; Quaggio et al., 1982). Those anions may be supplied by fertilization, by organic matter decomposition, and by gypsum application (Raji, 1991). Lime incorporation showed, therefore, be avoided in established pastures.

In order to study liming effects on the restoration of degraded pastures, an experiment was carried out using an established *Brachiaria decumbens* pasture,

growing on an Arenic soil. This experiment evaluated disking for lime incorporation in to the soil, and different amounts of dolomitic limestone, based on aimed values of BS and ECC.

MATERIAL AND METHODS

The degraded *Brachiaria decumbens* pasture was established on an Entisol of São Pedro, SP, Brazil (47°56'W, 22°30'S). Soil chemical analyses are shown in Table 1. This study tested two methods of lime application: 1. on the surface and 2. on the surface disk incorporation to the 20 cm of soil depth; limestone with three effective calcium carbonate (ECC) levels: 55, 70 and 90; and three aimed base saturation (BS) levels 40, 60 and 80%. Two controls were used: both with neither fertilization nor liming, but one included disking. Lime rates and types, and aimed BS values are presented in Table 2. The experiment consisted of a factorial randomized block design, with four replications. Plots measured 10 m², 2 m x 5 m.

Dolomitic lime was applied twice: in June 1995 and in June 1996. Limestone incorporation down to the 0.20 m soil depth was made in October 1995, since it caused plant death and a delayed plant regrowth in first year after disking. The lime contained 24 and 16% of CaO and MgO, respectively, with purity (percent CaCO₃ equivalent) of 83%. The ECC levels of 55, 70 and 90 were reached by mixing the lime from the same source but with distinct finenesses. Lime rates (Table 2) were calculated for the correction of the 0.20 m soil layer, reaching the aimed BS values, according to Raji (1991).

Cuts for pasture height homogenization was made in October 1995 and October 1996. In the same periods, the corrective fertilization was made with ordinary superphosphate (100 kg ha⁻¹ of P₂O₅), potassium chloride (enough to raise the K level in the CEC from initial values to 5%) and micronutrients (20, 15 and 10 kg ha⁻¹ of borax, zinc sulfate and copper sulfate, respectively). In the second year, liming and fertilization were based on the results of the soil analyses for each treatment. After each cut, in the rainy season (November to March), maintenance fertilization was made by five split applications of 60, 15 e 60 kg ha⁻¹ of N, P₂O₅ and K₂O, respectively. Corrective and maintenance fertilizations were made for high forage yield, following Corsi and Nussio (1994).

Botanical identification of plants mixed with *B. decumbens* was performed during the first year, and no more than 1% of the total biomass was *Paspalum sp* and some broadleaf species.

Table 1 - Soil chemical analysis of the Typic Quartzipsament.

Soil depth	MO	P resin	K	Ca	Mg	H+Al	Al	CTC	V	m	
m	pH CaCl ₂	g dm ⁻³	mg dm ⁻³	-----	mmol _c dm ⁻³	-----	-----	-----	-----	%	
0 - 0.20	4.0	19	2.5	0.6	6.4	4.2	34.4	7.5	45.6	25	40
0.10 - 0.30	3.9	18	3.0	0.3	5.0	3.0	38.0	10.0	46.3	18	55

Four randomized sub samples of forage (0.3 m x 0.6 m) from each plot were harvested by hand. Six cuts during the agrostological year 1995/1996 and seven 1996/1997 were performed. Forage was cut made 0.15 m above ground level, each 35 or 60 days in summer or winter, respectively, starting in October 1995. Forage and root dry matter yield were evaluated for each cut. Root samples were collected with soil tubes. Roots were separated from soil by washing and collecting then in a 0.75 mm mesh sieve. Forage and root samples were dried at 65°C for 48h to obtain dry matter.

In order to evaluate soil fertility, soil samples were collected at the beginning of the experiment, six months after liming and at the end of the growth period of each year, at depths of 0-0.05 m, 0.05-0.10 m and 0.10-0.30 m. Exchangeable cations and resin-exchangeable soil P were determined, according to the methods described by Raij et al. (1987). The pH value was measured in CaCl₂ (0.01 mol L⁻¹).

Orthogonal contrasts were used to compare treatments and analysis of variance was applied for the factorial treatments, in order to evaluate treatment effects and interactions among them. Means were compared by the F test. A regression analysis was also implemented.

Table 2 - Dolomitic lime rates (24 and 16% of CaO and MgO, respectively). ECC = effective calcium carbonate; BS = base saturation.

Incorporation	Treatments		Dolomitic lime	
	ECC	BS aimed	1995	1996
		%	----- Mg ha ⁻¹ -----	
Disking	55	40	1.3	0.8
Disking	55	60	2.9	2.3
Disking	55	80	4.6	3.8
Surface	55	40	1.3	0.6
Surface	55	60	2.9	1.3
Surface	55	80	4.6	3.5
Disking	70	40	1.0	0.4
Disking	70	60	2.3	1.3
Disking	70	80	3.6	2.1
Surface	70	40	1.0	0.2
Surface	70	60	2.3	0.9
Surface	70	80	3.6	2.3
Disking	90	40	0.8	0.4
Disking	90	60	1.8	1.2
Disking	90	80	2.8	2.0
Surface	90	40	0.8	0.3
Surface	90	60	1.8	0.8
Surface	90	80	2.8	2.0
Disking	Control	Control	0	0
Surface	Control	Control	0	0

RESULTS AND DISCUSSION

Soil chemical analysis results (surface soil layer of 0.20 m) collected before applying treatments indicate low BS, high aluminum saturation, medium contents of Ca and Mg and low contents of P and K, according Raij et al (1996). These results permit to foresee a response of the pasture to fertilization with P and K, and possible response to N due to the low organic matter soil content. Liming for pasture of *B. decumbens* is recommended by Werner et al. (1996) when BS is lower than 40%. The chosen experimental design did not permit to know if the pasture response was due to liming or fertilization, although all necessary conditions for liming response of pasture were present. The fertilization improved soil K and P contents (from 0.6 and 2.5 to 2.6 mmol_c dm⁻³ and 4.9 mg dm⁻³, respectively).

Forage dry matter yield was higher for all liming plus fertilization treatments in relation to control treatments. In the first year, the increase in forage dry matter due to both, liming and fertilization, were around 2 Mg ha⁻¹ in first year and 4 Mg ha⁻¹ in second year (Figure 1). Since weeds accounted for not more than 1% of the total biomass, the floristic composition was determined only for the first year.

Despite the fact that the same fertilization and liming rates were used in the two years, the increase in forage yield was markedly higher in the second year. This may be due to the gradual soil fertility improvement (Corsi e Martha Júnior, 1997) and to the recovery of plant structures, since pasture restoring is positively related to plant shoot and root yield (Oliveira, 2001). Climatic conditions did not seem to affect pasture yield, since there was no significant variation over the experimental period.

Soares Filho et al. (1992) found that fertilization with macro and micronutrients to restore a degraded *B. decumbens* pasture promoted higher forage yield in second year (13.1 Mg ha⁻¹) as related to the first year (3.8 Mg ha⁻¹), even with lower nitrogen fertilization (96 kg ha⁻¹) as compared to the present experiment.

Comparisons among treatments with fertilization plus liming, indicated no effect on forage yield of *Brachiaria decumbens*, for different lime types (different ECC), lime amounts to obtain aimed BS values, or disking.

ECC is considered to be an adjustment coefficient (Raij, 1991), which minimizes the differences among the lime types for the same soil BS aimed level. Soil BS obtained (from 42 to 58%) in the 0-0.05 m soil depth, may have supplied Ca and Mg to the forage during the pasture restoring process, which is in agreement with the findings of Werner et al. (1996) for established pastures of *Brachiaria decumbens*. As a matter of fact, even after two years of lime application, none of the aimed soil BS were reached (Figure 2).

Contrarily to the results obtained by Luz et al. (1988) and Soares et al. (1992), disking did not affect forage yield, for treatments with and without liming. Soares et al. (1992) found that disking decreased forage yield in the second year for *B. decumbens* pasture in a restoring process.

Liming and fertilization caused an increase ($P < 0.05$) in *B. decumbens* root dry matter in relation to controls for the 0-0.05 m and 0.05-0.10 m soil layers, during the second and first years (Figure 3). This might have been a consequence of decreasing the aluminum saturation and increasing macro and micronutrient soil availabilities in the layer 0.10 m, due to liming and fertilization. In the second year, an increase of 100% in root mass was observed for all treatments, in relation to the first year.

Disking for lime incorporation should be avoided since the root dry matter decreased in soil layers up to 0.30 m (Figure 4), probably due to root death and slow regrowth of *B. decumbens*. Soares Filho et al. (1992) also observed decreases in root production after disking in a pasture restoring process, even when fertilization was made.

Root mass was found to be affected ($P < 0.05$) only by lime ECC for the second year, in the 0-0.05 m soil layer. Lime ECC of 55 resulted in a higher root mass (7.1 Mg ha^{-1}) compared to 70 and 90 lime ECC values (5.9 and 5.5 Mg ha^{-1} , respectively). Mg is supposed to affect root growth more than Ca, since the Ca content was high ($> 7 \text{ mmol}_c \text{ dm}^{-3}$, according to Raji et al., 1996) for all the treatments in the 0-0.10 m soil layer (Figure 5 and 6). The content of Mg was high ($> 8 \text{ mmol}_c \text{ dm}^{-3}$, according Raji et al., 1996) in 0.05 m soil layer, only for lime ECC of 55 ($9.1 \text{ mmol}_c \text{ dm}^{-3}$), while for the lime ECC 70 and 90, Mg contents were medium, 6.2 and $7.4 \text{ mmol}_c \text{ dm}^{-3}$, respectively ($5 - 8 \text{ mmol}_c \text{ dm}^{-3}$, according Raji et al., 1996), for the same soil layer (Figure 7). Sanzonowicz et al. (1987) observed a positive effect of Mg fertilization on forage yield.

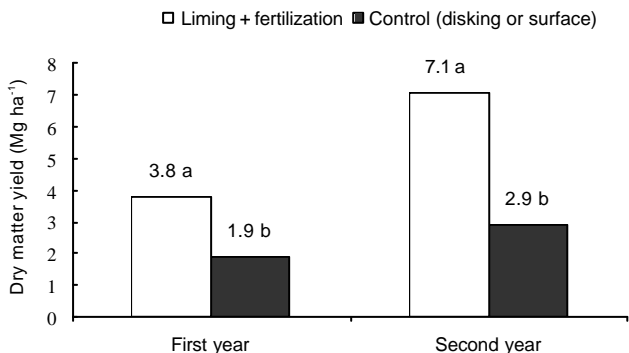


Figure 1 - Dry matter yield of the *Brachiaria decumbens* as a function of liming associated to fertilization.

*Means followed by different letter, within a experimental year, are different by F test ($P \leq 0.01$);
 ** CV de 29 and 16%, for first year and second year, respectively.

The two-year period was not long enough to the raise soil BS to the aimed levels (Table 2), which is in agreement with the findings of Caires & Fonseca (2000), who investigated the effect of surface liming application in no-tillage cropping, and by Guimarães (2000), who worked on *Brachiaria* and *Echinochloa* pastures. The deeper the soil layer and the higher the proposed BS level, the most difficult it was to reach the preset soil BS values (Figure 2). The aimed BS of 40% was only successfully reached for soil layers down to the 0.05m of depth. The BS remained quite low at the 0.10–0.30m depth, ranging from 21 to 25% (Figure 2), just a little higher than the 18% observed before the beginning of the experiment (Table 1).

Four hypotheses can be proposed to explain the results presented above: 1. the calculation of lime rates based on BS values to be reached in a soil with an established *B. decumbens* pasture (Raji et al., 1996) may underestimate the lime amount to be applied; 2. part of the lime amount applied did not react with the soil, as explained by Caires & Fonseca (2000); 3. the harvested forage may have removed some Ca and Mg; and 4. some of the applied Ca and Mg leached from the surface soil layer. Quaggio et al. (1982) observed annual leaching losses of 20% of Ca and Mg applied when lime was incorporated in a soil layer of 0.20 m depth, in a “Cerrado” soil, Hapludox.

In relation to Ca and Mg removals by the forage in the first year, they can be estimated around 15 and 10 kg ha^{-1} , respectively, and around 28 and 19 kg ha^{-1} in the second year. Those values were calculated based on the forage yield of treatments with liming and fertilization (Figure 1), and on mean Ca (4 g kg^{-1}) and Mg (2.75 g kg^{-1}) contents in the *Brachiaria brizantha* dry matter (Werner et al., 1996). These amounts are quite lower than those applied (188 and 70 kg ha^{-1} of Ca and Mg, respectively, corresponding to the lowest lime rates, 1100 kg ha^{-1} over the two years), but they account for 22% of Ca and 41% of Mg applied over the two years.

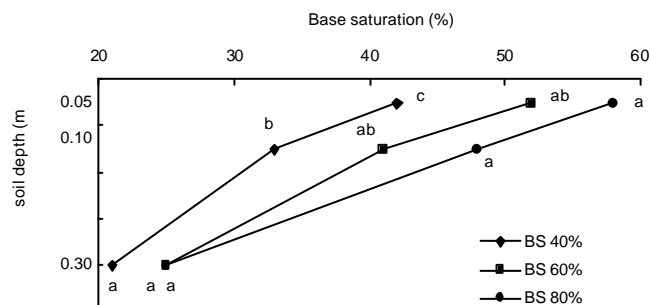


Figure 2 - Soil base saturation in the second year at different soil depths.

* Means, within soil depth, followed different letters are by Tukey test ($P = 0.05$).
 ** CV of 28, 33 and 43%, for soil depth 0-0.05, 0.05-0.10 and 0.10-0.30 m, respectively.

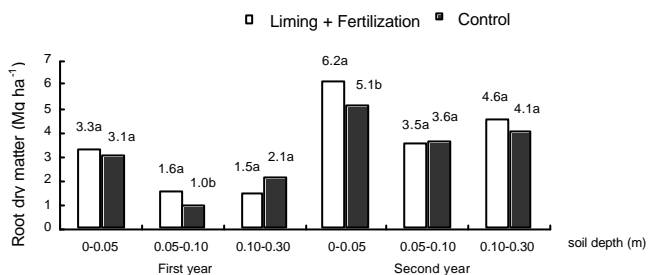


Figure 3 - *Brachiaria decumbens* root distribution in the soil. *Means, within a year and soil depth, followed by different letters are different by F test ($P \leq 0.05$); ** CV between 26 and 39%, depending to year and depth.

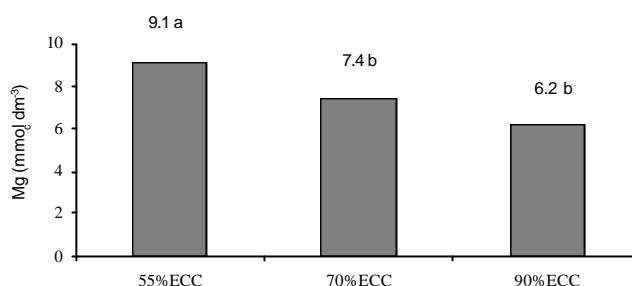


Figure 7 - Magnesium soil content as a function of Effective calcium carbonate (depth 0-0.05 m) at the end of experiment (1997). * Means, within a soil depth, followed by different letters are different by Tukey test ($P \leq 0.05$).

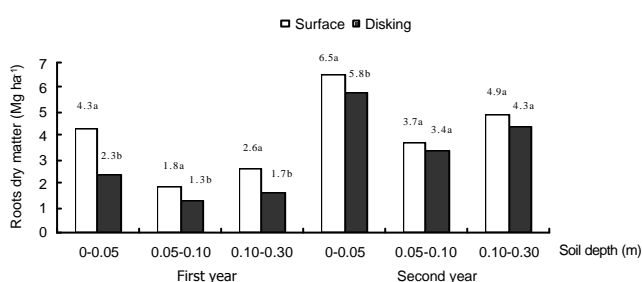


Figure 4 - *Brachiaria decumbens* roots as a function of lime application methods. * Mean, within year and soil depth, followed by different letters are different by F test ($P = 0.05$ and $P = 0.01$, in the first and second year respectively) ** CV ranged from 20 to 38% depending on year and depth.

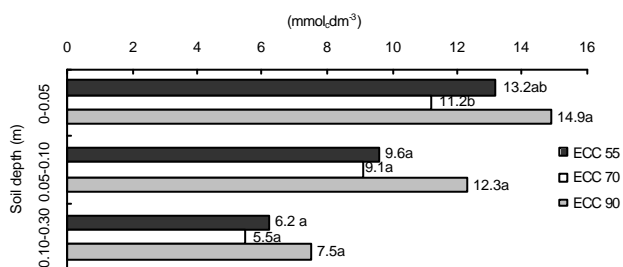


Figure 5 - Calcium soil content at the end of experiment as a function of the lime Effective calcium carbonate. *Means, within a soil depth, followed by different letters are different by Tukey test ($P \leq 0.05$).

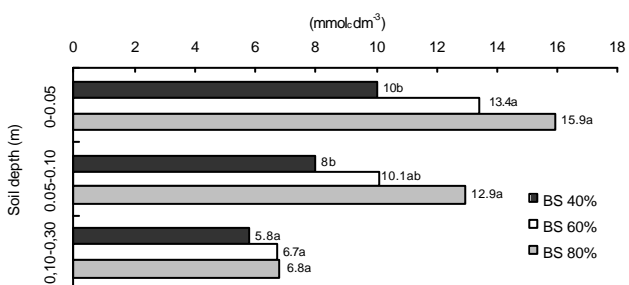


Figure 6 - Calcium soil content as a function of the soil Base Saturation at the end of experiment (1997). * Means, within a soil depth, followed by different letters are different by Tukey test ($P \leq 0.05$).

With reference to lime reaction in the soil, the data of Allen & Hossner (1991) indicated the presence of residual lime in soils of several sites in Texas (USA) after 10 years of liming. Residual lime content in the soil profile was calculated by determining the calcium carbonate equivalent and the residual lime itself, as well as calcite and dolomite contents in the residual lime through X-ray diffraction. Residual lime was found down to a 0.08m soil depth, for a 5.5 pH in the topsoil. When soil pH was lower than 5.5, like in the present experiment, all lime reacted, resulting in no residual lime, even in soil surface.

Liming increases soil BS and pH values and decreases Al saturation (Camargo et al., 1997), as indicated by the data obtained at the end of the experiment (Figures 8 and 9).

Liming increased CEC for the 0.05 m soil layer, but no effect was observed in deeper layers. The highest CEC value was observed for the aimed soil BS of 60% applying a lime ECC of 70 (Figure 10).

Soil organic matter contents decreased due to disking for lime incorporation, which may have caused the decomposition of organic matter (Figure 11), although the two years of *Brachiaria decumbens* pasture had the initial organic matter soil content increased.

Lime application on soil surface, with no incorporation, allows pastures to become a permanent cover cropping system, which is less vulnerable to erosion and nutrient losses, maintaining or even enhancing organic matter contents.

The low BS observed for the 0.10–0.30 m soil layer (Figure 2) associated to the low Ca and Mg contents (Figures 6 and 7), and to the high Al contents (Figure 9), may indicate that the organic matter (Miyazawa et al., 2000) and/or associated anions (Souza & Ritchey, 1986), supplied by dead forage remaining on the soil surface and by the high rates of fertilizers (ordinary superphosphate and potassium chloride), were not enough to reduce soil acidity and Al contents deeper than 0.10 m.

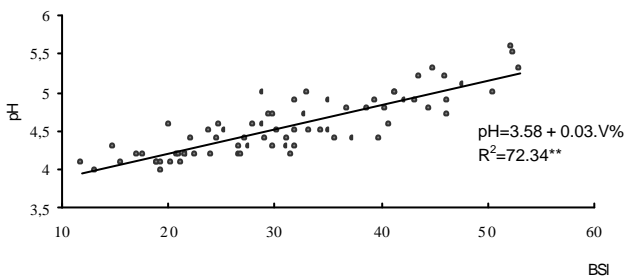


Figure 8 - Values of Base saturation obtained at the end of the experiment in relation to soil pH, for the depth 0-0.30 m.

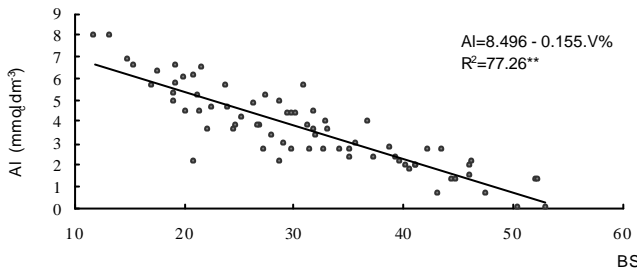


Figure 9 - Values of Base saturation obtained at the end of the experiment in relation to Al soil content, for the depth 0-0.30 m.

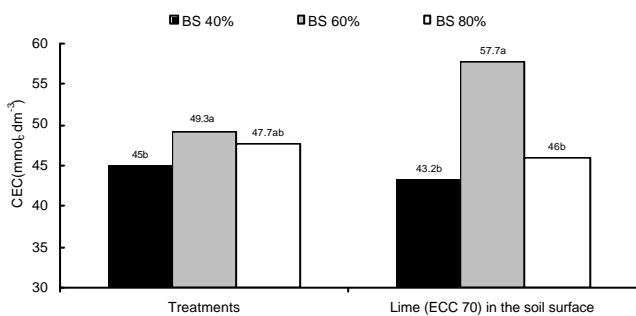


Figure 10 - CEC values as a function of Base saturation, for the soil depth 0-0.05 m, at the end of the experiment (1997).

*Means, within each collective column, followed by different letter are different by Tukey test ($P \leq 0.05$).

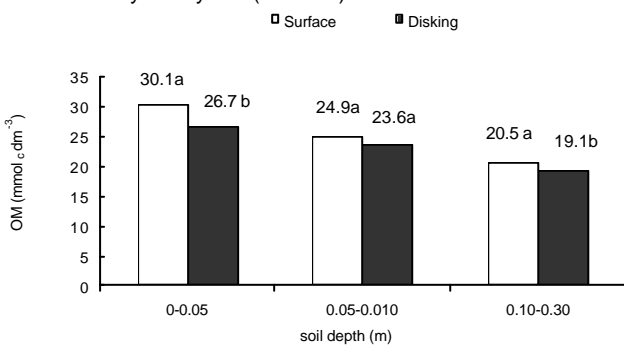


Figure 11 - Lime application methods in relation to soil organic matter content.

*Means, within a soil depth, followed by different letters are different by Tukey test ($P \leq 0.05$).

CONCLUSIONS

Liming and fertilization (N-P-K and micronutrients) prove an increase in forage and root yield, mainly in the second year after starting pasture rehabilitation, and recover *Brachiaria decumbens* degraded pastures.

For forage yield of *Brachiaria decumbens* the best treatment was no incorporation of lime by disking, which was harmful to root growth and decreased organic matter content of the soil layer down to the 0.30 m depth, over two years after starting pasture rehabilitation.

The preset BS values were not reached, even after two years of liming.

ECC Lime of 55, within a given BS, results in increases of root yield and magnesium soil content.

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