32. Increasing yield and carbon sequestration in a signalgrass pasture by liming and fertilization in São Carlos, São Paulo, Brazil

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1. Related practices

Liming, no-till, mineral fertilization; Grassland

2. Description of the case study

This study case aimed to evaluate the impact of liming and mineral fertilization of a Signalgrass pasture on C accumulation in surface and deeper layers of a Brazilian Oxisol. A 27-yr old Signalgrass pasture ((*Urochloa decumbens* cv. Basilisk Stapf (Syn: *Brachiaria))* was used in the trial. This pasture has been grazed in a stocking rate of one animal per ha and did not receive any liming and fertilizer until the beginning of the experiment. Treatments used in a 6-year trial are described in Table 127, and both limestone and fertilizers were applied to the soil surface with no soil plowing or disc-harrowing. Soil C stocks were calculated in equivalent soil mass, taking the native *Cerrado* (Savanna forest) soil mass as reference. Limed soil (0-100 cm) under non-fertilized pasture showed an annual increase of 1.71 tC/ha after 6 years over the soil under native vegetation. In contrast, fertilization of low productive and degraded pasture resulted in C accumulation rates varying from 5.4 to 7.2 t/ha/yr. The results illustrate that despite the C saturation in the surface soil layer, as evidenced by a sigmoid relationship between C contents in the whole soil and the clay fraction through the soil profile, the large proportion of C accumulation (from 55 to 68 percent) in deeper soil layers makes tropical pasture soils suitable long-term C sinks.

Table 127. Treatments applied to a Signalgrass pasture.

Treatments	Description
T00	Control, without liming and fertilizer
T0f€	No lime and fertilizer (200 kg/ha/yr N - ammonium sulfate, and 200 kg/ha/yr K_2O - KCl)
T2f€	Liming (2 t/ha in the first year plus 1 t/ha/yr in the second year) and fertilizer (200 kg/ha/yr N - ammonium sulfate, and 200 kg/ha/yr K_2O -KCl)
T4wf€	Liming (4 t/ha in the first year) and fertilizer (200 kg/ha/yr N - ammonium sulfate, and 200 kg/ha/yr K_2O -KCl)

€ Treatments also fertilized with single superphosphate (18% P2O5) to raise P in the soil to 10 mg/dm3.

3. Context of the case study

The studied area is located in the municipality of São Carlos, State of São Paulo, Southeastern Brazil (21°58'15.6" S and 47° 50' 55.33" W), 893 m above sea level. The prevailing climate is Cwa, following the Koeppen classification, and Tropical Moist according to the IPCC, with a mean annual temperature of 20°C and an average annual rainfall of around 1 360 mm. The soil is an Orthic Ferralsol according to FAO classification System (Hapludox, after US Soil taxonomy, and Red Yellow Latosol after the Brazilian Classification System (Calderano Filho *et al.*, 1998)), with 320 g/kg clay, and fragile structural stability. The native vegetation is considered an ecological transition zone, due to the occurrence of *Cerrado* (Savanna forest) and Mesophyle Semideciduous forest vegetation, a hardwood dry forest mainly driven by soil fertility and climate.

4. Possibility of scaling up

Liming and fertilization are essential issues to control soil acidity and lack of nutrients and improve pasture yield and quality. The practice of liming is commonly applied to crops, but for a long time, the liming recommendation for tropical pastures was a controversial subject due to doubts about the forage plants' needs and due to the efficiency of liming without incorporation at depth (Oliveira *et al.*, 2003). However, currently with new knowledge about the path of nutrients at-depth, and with the adoption of mineral fertilization in intensive areas, liming has become a routine technique in pasture formation, recovery, and maintenance. Brazil has around 112 million ha of cultivated pastures. Thus, the scaling up to livestock farms is possible.

5. Impact on soil organic carbon stocks

Table 128. Carbon stocks of a tropical Brazilian Oxisol under Signalgrass pasture affected by soil fertility management

Depth (cm)	Soil C stock (t/ha)				
	Natural vegetation	TOO	TOf	T2f	T4wf
0-10	23.2±0.8	30.3 b	59.9 a	54.4 a	53.0 a
10-20	22.9±1.0	23.6 b	25.0 b	41.8 a	38.9 a
20-40	25.1±1.1	40.4 a	40.9 a	40.7 a	41.2 a
40-60	21.5±0.4	32.5 a	32.8 a	28.3 a	26.7 a
60-80	15.3±0.2	24.7 a	23.7 a	27.0 a	21.1 a
80-100	16.9±0.8	19.6 a	21.1 a	22.5 a	27.6 a
Total	129	174 to			223

Means followed by the same letter, in the same soil depth, are not different by Tukey test at 5% level. The signal ± indicates the standard deviation (SD)

The highest amount of carbon was observed in soil samples under pasture, mainly in treatments with the addition of mineral fertilizer (t0f, t2f, and T4wf, Table 128). The carbon difference is greater on the surface (0-10 cm) than on deeper soil horizons due to the high input and accumulation of plant biomass, and a higher activity of soil organic matter. There was a general trend of SOC exponentially decreasing with depth. The carbon content is lower in an area with natural vegetation due to the lower supply of biomass and higher mineralization rate. Signalgrass has a robust root system that spreads deep into the soil, and the above-ground biomass also generates a significant amount of residual straw resulting in SOC increases. The N input stimulated SOC accumulation on the top layer. The total carbon stocks (0-100 cm) in the natural vegetation system (reference site) was 129 t/ha, while the carbon stocks determined for pastures ranged from 174 to 223 t/ha. The amount of carbon stock values found in this case study is similar to that determined at the same depth by Fisher *et al.* (1994), also of approximately 200 t/ha, in the Colombian savannas and to that found by Corazza *et al.* (1999), 150 t/ha, in *Cerrado* pastures cultivated with Signalgrass. Considering the 27-years-old pasture, the accumulation rate of total carbon stocks ranged from 1.7 to 3.5 tC/ha/yr. Compared to the soil under the natural vegetation, liming, and mineral fertilizer application to the Signalgrass pasture for 27 years had promoted sequestration of 6.1 to 12.8 t CO_2 /ha/yr from the atmosphere.

6. Other benefits of the practice

6.1. Benefits of soil properties

Liming improves P, Ca, and Mg availability, increases CEC, reduces Al and Mn toxicity, and improves soil aggregation and structure. Overall, liming improves the soil's ability to provide essential nutrients, as well as the plants' ability to uptake water and nutrients by enriching root growth and increasing soil microbial activity. Moreover, increasing soil pH and exchangeable bases stimulate OM decomposition and mineralization by promoting microbial activity (Haynes and Naidu, 1998; Fageria and Baligar, 2008). The results of this study case showed that high N levels decreased the soil pH and base saturation, while liming raised both parameters. Liming was required, especially as a source of Ca and Mg for Signalgrass. There were no effects of higher doses of limestone on the dispersion of soil particles and soil compaction. Thus, soil structure was preserved, as well as the macropores and, consequently, the hydraulic permeability or soil water conductivity. The field saturated hydraulic conductivity varied between 0.6 and 1.4 m/h, in treatments with mineral fertilization and high forage production (Primavesi *et al.*, 2004).

6.2 Minimization of threats to soil functions

Table 129. Soil threats

Soil threats	
Soil erosion	Lime and fertilizer application improve pasture growth and soil cover, and reduce soil erosion (Rocha Junior *et al.*, 2017)
Nutrient imbalance and cycles	Liming enhances mineralization and nitrification of organic N, (Bolan *et al.*, 2008; Primavesi *et al.*, 2008).
Soil acidification	Liming improves low soil fertility as a limiting factor for crop production limed by adding calcium (Ca) and magnesium (Mg) to the soil, increasing pH, and neutralizing the exchangeable aluminum (Al) content (Yamada, 2005, Souza and Lobato, 2004).
Soil biodiversity loss	Soil acidity correction increases the microbial activity (Albuquerque *et al.* 2003; Bolan *et al.*, 2008)
Soil compaction	Liming improved water aggregate stability and soil organic matter in the 0-10 cm layer (Bonini and Alves, 2011).
Soil water management	

6.3 On production

Compared to a control treatment with only mineral fertilization, liming and application of mineral fertilizer in a Ferralsol under Signalgrass produced between 9.8 to 13.5 t/ha of dry matter (Primavesi *et al.*, 2004, 2008). In addition to increased yield, other advantages of higher aboveground biomass of improved pastures were observed, thereby reducing soil temperature and organic matter decomposition. Oliveira *et al.* (2003) showed that limestone increased Signalgrass root production.

6.4 Mitigation of and adaptation to climate change

Well-managed pastures can increase the carbon stocks of the soil. However, the amount of SOC accumulation by improved pasture will depend on local climate conditions (rainfall and temperature), soil properties (texture and mineralogy), management practices, and economic resources (Batlle-Bayer, Batjes and Bindraban, 2010; Jantalia *et al.*, 2007; Haynes and Naidu, 1998). Batlle-Bayer, Batjes and Bindraban (2010) reviewed different studies that indicated the potential of lime-fertilized *Urochloa* pastures to increase soil carbon stocks ranged from 41 to 69 tC/ha to 0.2-m depth, with accumulation rates ranging from 0.2 to 0.7 tC/ha/yr.

Scurlock and Hall (1998) highlighted that the sustainable approach consists of managing the existing pastures to optimize carbon storage instead of the replacement of native vegetation by improved pastures. The potential for reduction of GHGs emissions by the Brazilian livestock is remarkably high (Bustamante *et al.*, 2012), and it should be accompanied by reduction of deforestation, secondary forest regeneration, enteric fermentation reduction, pasture restoration, and elimination of fire in pasture management. Pasture restoration is one of the leading strategies of the Brazilian governmental program "Low-Carbon Agriculture" to reduce or compensate the carbon emissions (Sá *et al.*, 2017). Productivity gains in livestock have been pointed out as a promising alternative to achieve climate change mitigation together with economic growth (Silva *et al.*, 2016; Silva, Ruviaro and Ferreira Filho, 2017); Oliveira *et al.* (2017) showed that pasture intensification lead to a reduction in GHG emissions, considering emissions per unit of production increase, and beyond that, an increase in soil carbon storage was achieved.

6.5 Socio-economic benefits

Table 130 shows that soil acidity control by liming also provides economic benefits. Based on Oliveira *et al.* (2003), forage yields were higher in pastures that received (i) only liming and (ii) liming and fertilization than in pastures that received (iii) no input or (iv) only fertilization. Considering dry matter yield results, the animal stoking values, and weight gains were estimated. Additionally, the efficiency was calculated considering the market price of meat and limestone, and the cost of liming operation. The economic advantage of liming was highlighted considering that for every US dollar invested in liming it has led to a return on beef production of up to US$2.20 using limestone only and up to US$3.50 combining limestone and fertilizer.

Table 130. Simulation of animal stocking, carcass gains, and economic return for limestone and fertilizer use in beef cattle pastures

	Degraded Pasture	Limed Pasture	Fertilized Pasture	Limed and Fertilized Pasture€	Average without liming	Average with liming
Dry matter yield (kg/ha)	4,4	5,9	16,4	19,0	14,4	16,8
Stocking (AU/ha)&	0,9	1,3	3,5	4,1	3,1	3,6
Weight gain (kg/ha)†	231,6	315,0	869,0	1010,3	762,8	894,5
Carcass yield (@/ha) £	7,7	10,5	29,0	33,7	25,4	29,8
Economic return§	-	2,2	-	-	-	3,5

Assumptions: Grazing efficiency = 70%; Dry season = 180 days; wet season = 185 days

€ Liming = 1.5 t ha^{-1}; Fertilizer = 100 kg ha^{-1} N; P = 15 ppm, and K_2O = 3%

& AU = Animal unit = 450 kg

† System starts with young male cattle (300kg) to be finished. Daily dry matter consumption = 2% of living weight. Daily weight gain: dry season = 0.25 kg per day, wet season = 0.7 kg per day

£ Carcass yield = 50% efficiency, 1 @ = 30 kg living weight.

§ (@ Yield with lime – @ Yield without lime) (liming costs)$^{-1}$. Prices: @ = US$45.00; lime = US$29.40 per ton; liming operation = 0.5 h X US$25.50 per h. US$ 1.00 = R$5.10

7. Potential drawbacks to the practice

7.1 Tradeoffs with other threats to soil functions

Table 131. Soil threats

Soil threats	
Nutrient imbalance and cycles	High doses of N fertilizer with low liming can result in losses of nitrate to the subsoil, with Ca and N-NO3 binding, leading to acidification of the surface layer, with consequent loss of N-NO3 and K (Primavesi *et al.*, 2008).
Soil salinization and alkalinization	Surface application of high lime rates promoted chemical stratification resulting in dramatic increases in topsoil pH and exchangeable Ca and Mg levels with minimal mitigation of subsurface soil acidity in croplands no-till areas (Nunes *et al.*, 2019).

Soil threats	
Soil erosion	Excessive increased in soil pH values were related to increased clay dispersion, destroyed soil aggregates, and reduced infiltration of Oxisols (Haynes and Naidu, 1998; Costa *et al.*, 2004; Hunke *et al.*, 2015).
Soil compaction	
Soil water management	

7.2 Increases in greenhouse gas emissions

An estimate of the net GHG balance (soil C sequestration minus emissions of nitrous oxide and methane) made by Oliveira *et al.* (2017) is presented in Table 132. Intensive systems demand more nutrient inputs (fertilizer and lime), and lead to an increase in animal stocking rates, increasing the total emissions. However, there is also a greater increase in C storage in the soil leading to a final balance for this system is more positive.

Table 132. The balance between GHG emissions and removals, considering two beef cattle production systems

Adapted from Oliveira et al. (2017)

Pasture management	Animal stocking	Soil C rate [†]	C storage[£]	CH_4 animal[€]	N_2O soil[§]	CH_4 soil[€]	CO_2 Limestone[&]	Total emissions	Net difference
	n per ha	t/ha/yr	t CO_2eq/ha/yr						
Extensive	2.04	1.7	6.24	2.95	0.00203	0.00068	-	2.9527	3.29
Intensive	3.13	3.13	11.49	5.55	0.00068	0.00068	0.47	6.0214	5.4686

[†] Results for the 0-1.0 m depth

[£] Conversion factor = 3.67

[€] Emission metrics for CO2 -equivalent emissions (100-year GWP): 28 (IPCC, 2014)

[§] Emission metrics for CO2 -equivalent emissions (100-year GWP): 265 (IPCC, 2014)

[&] 0.13 t C-CO2 per t of limestone, with 50% emission (De Klein *et al.*, 2006). Limestone doses = 2 t/ha

7.3 Conflict with other practice(s)

Liming recommendation for pastures was a controversial subject due to doubts about the response of tropical pastures. However, with new knowledge about the detailed path of nutrients and the adoption of mineral fertilization in intensive areas, new concepts have been created, and liming has become a routine technique both in the formation and maintenance or restoration of pasture areas, having a relevant role in the efficiency and sustainability of pasture (Cantarella *et al.*, 2002; Martha Jr. and Vilela, 2002; Primavesi *et al.*, 2008).

Soil plowing and disc-harrowing to incorporate limestone in soils cultivated with pastures was also a controversial practice. The slight increase in forage production observed when the limestone was incorporated into the soil (Primavesi *et al.*, 2004) did not compensate for the high-cost machine operation (Caires, Banzatto and Fonseca, 2000). Oliveira *et al.* (2003) observed that disc harrowing harmed the forage root system development and caused a decrease in the soil carbon levels. Primavesi *et al.* (2008) stated that the adequate amounts of limestone applied consists of reaching optimum level of soil base saturation needed for forage growth (35 percent to 40 percent) with complimentary annual surface broadcast to control soil acidity caused by mineral nitrogen fertilizer used.

8. Recommendations before implementing the practice

The soil chemical analysis is essential for the liming and fertilization recommendation, aiming for economically viable and environmentally correct livestock production (Cantarella *et al.*, 2002). Guidelines for liming and fertilizer application are essential tools to integrate and transfer the results of research on soil fertility and plant nutrition to farmers (Cantarella, Raij and Quaggio, 1998). The first and most critical step of the chemical analysis concerns the soil sampling process, and then the analysis carried out in a high-quality soil analysis laboratory (Bernardi *et al.*, 2002; Souza and Lobato, 2004).

9. Potential barriers to adoption

Table 133. Potential barriers to adoption

Barrier	YES/NO	
Biophysical	Yes	CO_2 emissions from lime are GHG sources (Mazzetto *et al.*, 2015).
Cultural	Yes	Many times, the extensive managed pastures do not receive nutrients input or receive amounts below plant's needs (Cantarella *et al.*, 2002) based on a wrong concept of tropical grasses are rustic and can produce anyway.

Barrier	YES/NO	
Social	Yes	Low-productive livestock farms do not invest in pasture maintenance and amelioration (Cantarella *et al.*, 2002; Martha Jr. and Vilela, 2002) due knowledgement lack of how adequately managed productive pasture.
Economic	No	Liming is the most common way to control soil acidity in Brazil due to its favorable cost-benefit and positive effects on fertilizer efficiency (Cantarella *et al.*, 2002; Yamada, 2005; Fageria and Baligar, 2008).
Institutional	No	Soil testing facilities are spread in all agricultural regions, and liming recommendations are well-known and adopted for many crops (Cantarella, Raij and Quaggio, 1998; Bernardi *et al.*, 2002; Souza and Lobato, 2004).
Knowledge	No	Several experimental results show the positive effects of liming acidic soils, and there are established efficient recommendations (Fageria and Baligar, 2008).
Natural resource	No	In Brazil, there is many carbonate rocks with potential for agricultural use and production occurs close to agricultural regions (Nahass and Severino, 2003).

Photo

Photo 63. Experimental plots of Signalgrass pasture: control (T00) on left and limed and fertilized (T4wf) on right

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