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Soil Quality and Grass Yield in a Mined Area under Poultry Litter Application in Minas Gerais State, Brazil

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Abstract

Bauxite mining causes substantial changes in the environment, especially in its most fragile portion, the soils. Animal manures may enhanced the plant growth on degraded mined soils, due to (i) the release of plant nutrients and also (ii) improvements on soil organic matter, microbial activity, water retention and others soil properties. In the present study, we evaluated the short-term changes on soil quality and biomass production in a bauxite mined area under reclamation, fertilized with Poultry Litter (PL) (0, 10, 20 and 40 Mg ha^{-1}) and cultivated with the grass *Brachiaria brizantha*. Stripping and stockpiling of top soil notably decreased soil fertility. Moreover, the Carbon Management Index (CMI) drastically decreased after mining. PL application presented a positive effect in emergent soil properties, such as N and P contents, cation exchange capacity and CMI. The application of high doses of PL was associated with short-term improvements in soil quality, which yielded to a high *B.Brizantha* biomass production, reaching 24 Mg ha^{-1} (dry mass) when soil was fertilized with 40 Mg ha^{-1} of PL. Finally, we recommend the application of 34 Mg ha^{-1} of poultry litter in bauxite mined areas in Minas Gerais State, Brazil.

Keywords: Land Reclamation; Animal Manure; Carbon Management Index; Soil Quality Indicators; Topsoil; Bauxite Mining

Abbreviations

PL: Poultry Litter; SOM: Soil Organic Matter; CEC: Cation Exchange Capacity; CMI: Carbon Management Index; SOC: Soil Organic Carbon; LC: Labile Carbon

Introduction

Surface mining is often associated to environmental impacts and land degradation [1]. In Brazil, the third biggest bauxite producer in the world, the surface mining of bauxite causes notably environmental disturbance. Despite of its substantial economic benefits, a single bauxite mine can be responsible for the degradation of up to 100 ha of land per year [2]. In this case, land degradation is mainly caused by vegetation and topsoil removal, besides drastic changes on topography and hydrologic regime. In Minas Gerais State, Brazil, the recent mining disaster reiterated the need of strategies to decouple the mining activity of environmental negative impacts [3].

The first goal of reclaiming severely degraded areas is to promote fast plant cover of the area in order to protect the soil from erosion, and to input new biomass/carbon to the system [4]. Particularly for bauxite mined sites in Minas Gerais State, considering the slopes of these areas and the negative effects of erosion processes during land reclamation [5], the use of fast growing plants with high biomass yield, such as grasses, is one of the best options. Moreover, most of these areas were previously used as pastures for beef and dairy cattle production.

During the land reclamation, the topsoil removed before mining is redistributed over the area, since this material is supposed to being a better option to grass establishment comparing to the remaining substrate [6]. However, this practice by itself it is not enough to ensure environmental recovery after mining activities, mainly because the nutrients and C losses during the stripping and stockpiling of topsoil [7]. In this context, the application of animal manures has emerged as a feasible alternative to soil reclamation in disturbed lands.

Animal manures may enhanced the plant growth on degraded mined soils, due to (i) the release of plant nutrients and also (ii) improvements on Soil Organic Matter (SOM), microbial activity, water retention and others soil properties [8]. In Brazil, Poultry Litter (PL) is quite available in some regions with large areas degraded by mining activities, such as Minas Gerais State. The use of PL in mined areas presents not only the benefits discussed above, but also represents an alternative disposal for this residue, preventing environmental pollution.

The mining companies have the legal and social commitment of returning the areas for the owners with the same production level previously observed before mining. The deadline for land reclamation varies between 3 to 6 years, a short period when considering the severe disturb associated to the bauxite extraction. The periodic evaluation of reclamation process is essential to development of effective strategies to recovery the plant production in degraded soils. In this sense, this study aimed to evaluate the first year of reclamation process in bauxite-mined areas cultivated with *Brachiaria brizantha* under different rates of PL application. Specifically, we wanted (i) to compare some soil quality indicators, such as N and P contents, C management index and cation exchange capacity during the land reclamation; and (ii) evaluated the grass yield in the first year after reclamation in a bauxite mined-area in Minas Gerais State, Brazil.

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Materials and methods

Site characterization and experiment design

The study was carried out in Minas Gerais State, Brazil. The experiment was set up in an area of bauxite that had been strip-mined in 2009. Before mining, any soil above the ore (topsoil) was stripping and stockpiling; returning one year later during the topographic reconfiguration of to the original site. Later, soil decompaction down to 60 cm deep was carried using a ripper pulled by a bulldozer. The original soil was classified as an Oxisol [9], dystrophic and clayey (580 g kg^{-1} clay, 90 g kg^{-1} silt, and 330 g kg^{-1} sand).

The experiment was set up under a completely randomized design, with four replicates. The plots (12 m^2 each) were fertilized with PL at 0, 10, 20, or 40 Mg ha^{-1} (dry basis). The chemical composition of the PL was (g kg^{-1}): C: 365; N: 21.7; P: 17.8; K: 2.1; Ca: 9.2; Mg: 1.8; Na: 1.6; Cu: 0.12; Mn: 0.97; Fe: 16.4; and Zn: 0.99. All the plots also received lime (1.5 Mg ha^{-1}). The PL and lime were incorporated into the 0-20 cm soil layer by hand hoeing.

Twenty days after PL application, *Brachiaria brizantha* cv. *Marandu* (C4 African grass) was seeding in 0.25 m spaced furrows (50 kg viable seeds ha^{-1}). Weed control was done using selective herbicides as required. The above-ground biomass production was evaluated within 6, 9 and 12 months after the field experiment establishment. The biomass samples were taken from a 1 m^2 plot, always at least 0.5 m from the borders. A subsample was dried in a forced-air circulation oven (62°C for 72 h) in order to obtain the dry matter. After sampling, the plants that remained in the plots were trimmed with a mower and left on the soil surface.

Soil samplings and analysis

Soil sampling was performed in three different intervals: before mining, after the topsoil was applied and redistributed over the disturbed area and one year after the field experiment had been established. Soil samples were taken from eight different points of each subplot using a probe at 0-0.1, 0.1-0.2 and 0.2-0.4 m depth. Finally, all the soil samples were air dried, mixed and sieved through a 2 mm sieve for subsequent laboratorial analyses.

The soil pH was determined in water (soil/solution ratio 1:2.5 v/v). Al^{3+}, Ca, and Mg were extracted with a 1 M KCl solution. P, Fe, Zn, Cu, Mn, Na and K were extracted by Mehlich I. Total acidity ($H^{+}Al$) was extracted with calcium acetate at p^H 7.0. $H^{+}Al$ and Al^{3+} were quantified by titration with a 0.025 M NaOH solution. Ca, Mg, Fe, Zn, Cu and Mn soil contents were quantified by atomic absorption spectroscopy. P was quantified by colorimetry and Na and K soil contents by flame photometry. The soil N was quantified by Kjeldahl distillation [10]. For more details about these procedures, see [11].

The Carbon Management Index (CMI) [12] was calculated using the follow equation:

$$CMI = \frac{SOCaf}{SOCbf} * \frac{\frac{LCaf}{NLCaf}}{\frac{LCbf}{NLCbf}} * 100$$

Where,

CMI = Carbon Management Index

SOCaf = Total organic carbon in the soil after mining

SOCbf = Total organic carbon in the soil before mining

LCaf = Labile carbon in the soil after mining

NLCbf = Non-labile carbon in the soil after mining

LCaf = Labile carbon in the soil before mining

NLCf = Non-labile carbon in the soil before mining

The Soil Organic Carbon (SOC) was assessed using wet oxidation with external heating [13], whilst the Labile Carbon (LC) quantification was carried out using the oxidation by $KMnO_4$ (33 mmol L^{-1}), according to [14]. The Non-Labile Carbon (NLC), which is equivalent to the residual C not oxidizable by $KMnO_4$ was determined by subtraction (NLC = SOC – LC). As pointed in the equation, we used the soil C contents before mining as reference (CMI=100). For further details and discussion about SOC and LC in this area, see [15].

Statistical analysis

The statistical analysis of data was performed in a completely randomized design (four replicates per PL rate). All the data from this experiment was combined and analyzed using analysis of variance by the statistic F test, considering a 5% level of significance. When achieving significant statistical values, the means were then analyzed through Tukey's test ($\alpha = 5\%$). Statistical regression analysis was used to investigate the effect of different PL doses on soil indicators and grass yield (data not shown).

Results and Discussion

Soil fertility indicators

The comparison of soil quality indicators before and after mining showed that the stripping and stockpiling of topsoil notably decreased the soil fertility (Table 1). During a mining operation, the vegetation is removed, so the topsoil can be pushed aside in stockpiles until post mining reclamation. The removal and storage remarkably alter topsoil properties, being associated to C and nutrient losses, drastically decreasing on microbial activity, disruption of soil structure and p^H shifts [7]. In this sense, a proper handling and storage of topsoil materials can decrease the quality loss and foment the land reclamation process. Moreover, these changes reiterate the need of additional strategies besides the topsoil use in bauxite-mined areas.

One year after mining, was observed an improvement on soil fertility, mainly in plots that received PL (Table 1). All the plots were liming. However, the comparison between the pH values in plots that not received PL with those which received showed that the PL application had a positive effect on soil pH, irrespective of PL dose (Table 1). After one year, plots which received PL had a pH at least one unit greater than plots without PL, irrespective of depth. Most of solid animal manures contain significant concentrations of Ca, Mg and $CaCO_3$ [16]. In this sense, the application of animal manures move soil pH towards neutrality in acidic soils, thus improving nutrient availability, especially P [16]. This is also favorable for plant growth and a variety of beneficial microbial processes. Accordingly, [17] found that 160 Mg ha^{-1} (wet mass) of cattle feedlot manure added to acidic Gray Luvisols (pH 4.1 to 4.8) led to a similar increase in soil pH as the addition of 5 Mg ha-1 of lime (97% $CaCO_3$). Therefore, animal manures must be regarded not only as a source of nutrients, but also as a beneficial soil conditioner for mined areas.

Table 1: Soil fertility indicators in a bauxite mined area under reclamation in Minas Gerais state, Brazil.

Time of sampling and PL rate[1]	pH	N	P	K	Ca	Mg	Al	CEC	m	V
		mg dm^{-3}		cmolc dm^{-3}					%	
0-0.1 m										
Before mining	6.2a	386.8c	5.5d	0.1c	1.8b	1.3c	0.03b	3.2c	0.9b	57.2b
After mining	4.42b	78.2d	0.6e	0.05d	0.05c	0.1d	1.5a	1.7d	88.2a	1.7c
1 yr 0.0 PL	5.2ab	418.7c	3.3d	0.1c	1.6b	1.2c	0.02b	2.9c	0.7b	57.0b
1 yr 10.0 PL	6.3a	997.6b	23.1c	0.4b	2.0b	1.6c	0.02b	4.0bc	0.5bc	66.1ab
1 yr 20.0 PL	6.4a	1187.8b	77.4b	0.6b	3.2a	2.2b	0.03b	6.1b	0.5bc	72.6ab
1 yr 40.0 PL	6.4a	1901.1a	135.0a	1.7a	3.4a	3.1a	0.03b	11.3a	0.3c	82.9a
0.1-0.2 m										
Before mining	6.2a	301.5b	4.5c	0.1c	1.8a	1.3a	0.03b	3.2b	0.9c	57.2b
After mining	4.1b	85.4c	0.5d	0.04d	0.05c	0.1c	1.6a	1.8c	89.4a	1.7d
1 yr 0.0 PL	4.8b	336.2b	2.1c	0.1c	1.1b	0.7b	0.04b	1.9c	2.1b	42.3c
1 yr 10.0 PL	5.7a	710.1a	9.0b	0.2c	1.2b	1.3a	0.04b	2.7b	1.5bc	49.5c
1 yr 20.0 PL	5.9a	679.4a	8.6b	0.6b	1.8a	0.8b	0.04b	3.2b	1.2bc	47.8c
1 yr 40.0 PL	6.2a	775.2a	19.9a	1.4a	2.0a	1.7a	0.02b	5.4a	0.4d	69.2a
0.2-0.4 m										
Before mining	6.2a	219.3b	2.8c	0.1c	1.8a	1.3a	0.03b	3.2a	0.9c	57.2a
After mining	4.4b	88.7c	0.5c	0.04d	0.05c	0.1b	1.4a	1.6c	88.1a	1.7c
1 yr 0.0 PL	5.3b	260.8b	1.7c	0.1c	0.3b	0.8a	0.04b	1.2c	3.2b	27.9b
1 yr 10.0 PL	5.5b	493.5a	5.6b	0.1c	0.8ab	1.1a	0.04b	2.0b	2.0bc	52.1a
1 yr 20.0 PL	5.5b	505.8a	4.1b	0.2b	0.6ab	1.4a	0.04b	2.2b	1.8bc	40.4ab
1 yr 40.0 PL	5.7ab	443.7a	18.3a	0.4a	1.2a	1.2a	0.04b	2.8a	1.4bc	50.0a

[1]Before mining: soil sampling in the pasture area before topsoil removal and mining. After mining: soil sampling after mining and topsoil distribution, but before poultry litter application. 1 yr 0.0 PL, 1 yr 10.0 PL, 1 yr 20.0 PL, 1 yr 20.0 PL: soil sampling one year after mining in plots under *Brachiaria brizantha* cultivation and fertilized with 0, 10, 20 and 40 Mg ha^{-1} of poultry litter, respectively. CEC: Cation Exchange Capacity. M: aluminum saturation. V: bases saturation. Letters represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %).

Plots that received PL showed greater N contents (Table 1). The PL dose had a positive linear effect (p<0.01) on soil N contents at 0-0.1 m depth (data not shown). However, in the others depths, the N contents not differed among doses one year after PL application (Table 1). Nitrogen is a macronutrient that is required by grasses in large amounts and is frequently deficient in Brazilian soils, limiting grass production [18]. Moreover, the stripping and stockpiling of topsoil cause notably losses of N (Table 1). In this sense, PL application may be a good strategy to recovery the N contents in bauxite mined areas. Moreover, unlike synthetic fertilizers, a portion of the N in PL is in mineral form (NH_4^+) and is readily available for plant uptake, whilst other portion is present in organic form, slow released during the mineralization process [19]. The provision of different N forms may assure the meet of N requirements of the grass longer, besides avoiding N losses.

Plots which received PL showed greater soil P contents (Table 1), with the PL dose having a positive linear effect (p<0.1) on soil P contents, irrespective of depth (data not shown). Moreover, plots that received the application of 40 Mg ha-1 of PL presented greater soil P contents in all depths evaluated (Table 1). The high content of P in poultry litter (17.8 g kg^{-1}) is associated with the increments on soil P contents, even in the deeper soil depths. Similar to N, P is a macronutrient that is required by grasses in large amounts and it is frequently deficient in bauxite-mined areas.

Regarding P dynamics, one of the benefits of animal manures is that the slower mechanism of P release "minimizes" the risk of subsequent binding in soil minerals comparing to fertilizers derived from inorganic sources [20]. In eroded soils, [21] showed that animal manure was much better at restoring productivity than inorganic P fertilizer (even at rates up to 400 kg ha^{-1}), because the fertilizer was likely to be immobilized by high levels of calcium carbonate in the exposed soil surfaces. In highly weathered Brazilian soils, similar mechanisms can bind the P to iron and aluminum oxides, making the P unavailable to plant uptake.

The Cation Exchange Capacity (CEC) of a soil is primarily dependent on the amount and type of clay, SOM, as well as the amount of Fe, Al and Mn oxides. SOM and clay particles have large surface areas and have a large number of exchange sites. The intrinsic CEC of animal manures can vary widely, and their application to soils will often increase CEC [16], mainly because its effects on SOM. The PL dose had a positive linear effect (p<0.01) on soil CEC, irrespective of depth, where plots which received 40 Mg ha^{-1} showed the greater CEC (Table 1). This reinforce the role of the PL improving the soil quality after bauxite mining, since CEC is an integrated indicator for soil physical and chemical properties that are strongly related to crop yield [22]. Despite the liming effects, the high amount of Ca, Mg, Na

Table 2: Plant micronutrients and sodium in soils of a bauxite mined area under reclamation in Minas Gerais state, Brazil.

Time of sampling and PL rate[1]	Fe	Zn	Cu	Mn	Na
	mg dm^{-3}				cmolc dm^{-3}
			0-0.1 m		
Before mining	54.8bc	1.1c	0.9c	6.9c	0.0b
After mining	65.6bc	3.4c	2.1c	8.6c	0.0b
1 yr 0.0 PL	38.6c	2.7c	0.9c	8.1c	0.0b
1 yr 10.0 PL	95.0b	6.3bc	5.7bc	13.0c	0.0b
1 yr 20.0 PL	90.7b	11.4b	11.1b	21.7b	0.1a
1 yr 40.0 PL	110.6a	24.0a	28.2a	39.9a	0.1a
			0.1-0.2 m		
Before mining	45.8c	1.0c	0.7c	5.2b	0.0b
After mining	57.9c	3.9b	2.1c	8.1b	0.0b
1 yr 0.0 PL	56.9c	1.7c	1.1c	6.4b	0.0b
1 yr 10.0 PL	109.5b	3.4b	3.1b	8.0b	0.0b
1 yr 20.0 PL	103.0b	4.1b	3.5b	8.2b	0.0b
1 yr 40.0 PL	122.6a	10.9a	9.4a	20.8a	0.3a
			0.2-0.4 m		
Before mining	35.7c	0.6c	0.9b	4.1b	0.0a
After mining	55.9b	2.9b	1.7b	7.5ab	0.0a
1 yr 0.0 PL	56.9b	1.1c	0.8b	5.5b	0.0a
1 yr 10.0 PL	77.3a	1.9bc	1.4b	5.9b	0.0a
1 yr 20.0 PL	82.9a	1.5bc	0.9b	4.1b	0.0a
1 yr 40.0 PL	76.5a	4.3a	3.8a	9.1a	0.0a

[1]Before mining: soil sampling in the pasture area before topsoil removal and mining. After mining: soil sampling after mining and topsoil distribution, but before poultry litter application. 1 yr 0.0 PL, 1 yr 10.0 PL, 1 yr 20.0 PL, 1 yr 20.0 PL: soil sampling one year after mining in plots under *Brachiaria brizantha* cultivation and fertilized with 0, 10, 20 and 40 Mg ha^{-1} of poultry litter, respectively. Letters represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %).

and K in the PL is also associated with the increments on the bases saturation one year after PL application (Table 1).

Micronutrients are required in small amounts by plants and they have a range of safe and sufficient intake. The PL application was also associated with the increase in micronutrients availability in soil (Table 2). The application of high doses of animal manures may lead to excessive concentrations of micronutrients in soil, as well as sodium [23]. However, none of the micronutrients assessed in this research showed values above the critical limits. Besides element accumulation, environmental problems such as nitrate leaching to groundwater, P runoff to surface water and leaching, and release of greenhouse gases to the atmosphere may be associated to the application of high rates of animal manure on soil [24]. Thus, since the PL application is supposed to act mitigating an environmental problem (land degradation), is mandatory the continuously evaluation of these areas in order to detect possible negatives impacts associated to this practice.

Carbon management index

Since SOM plays such a key role in soil productivity by affecting almost all physical, chemical and biological properties, successful land reclamation depends on recreating a surface horizon with enough SOM to sustain productivity [25]. Our previous study showed that the cultivation of *B. brizantha* fertilized with PL supported the

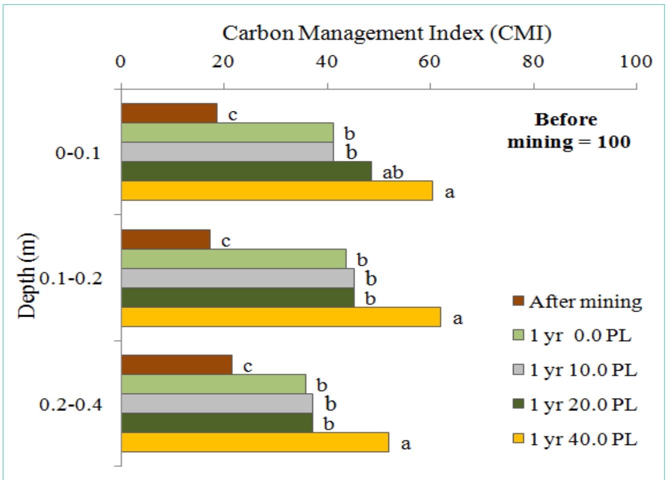

Figure 1: Carbon Management Index (CMI) in a bauxite mined area under reclamation in Minas Gerais state, Brazil.
Before mining: soil sampling in the pasture area before topsoil removal and mining.
After mining: soil sampling after mining and topsoil distribution, but before poultry litter application. 1 yr 0.0 PL, 1 yr 10.0 PL, 1 yr 20.0 PL, 1 yr 20.0 PL: soil sampling one year after mining in plots under *Brachiaria brizantha* cultivation and fertilized with 0, 10, 20 and 40 Mg ha^{-1} of poultry litter, respectively. Letters represent statistically significant differences between land uses in the same depth, according the Tukey test (5 %).

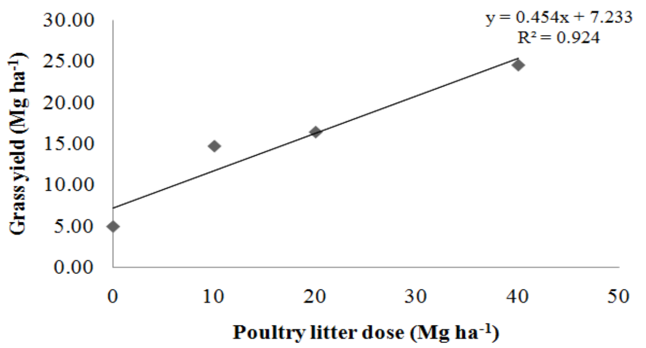

Figure 2: *Brachiaria brizantha* yield (Mg ha^{-1}) after 1 year of cultivation (3 cuts) in a bauxite mined area under reclamation with different doses of poultry litter in Minas Gerais state, Brazil.

recovery of bauxite-mined soils by increasing SOC and LC [15]. The CMI expresses the soil quality in terms of increments in the SOC and in the proportion of LC compared to a reference soil, in our case the soil before mining, which arbitrarily has a CMI of 100. CMI values lower than 100 are indicative of negative impact of management practices on SOM and soil quality; meanwhile values greater than 100 are indicative of positive effects of the management practices on soil quality [12]. In our study, the CMI proved to be a useful indicator to evaluate the reclamation process in bauxite-mined areas.

The stripping and stockpiling of topsoil drastically decreased the CMI (Figure 1). The removal and storage notably alter topsoil properties, being associated to C and nutrient losses, decreasing of microbial activity, disruption of soil structure and pH shifts [7]. All these aspects contribute to the low CMI in this area after mining, with values around 20 in all depths assessed. After 1 year, the cultivation of the *B. brizantha* without PL more than doubles the CMI values. However, the greater results were observed in plots that received PL application, mainly in higher doses (Figure 1).

SOC and the C lability have directly influence in soil physical, chemical and biological attributes as well as the self-organization capacity of soils [12,26]. In addition, C lability is associated with nutrient mineralization and can make an important contribution to nutrient availability, nutrient cycling and biomass production. The increase on CMI, mainly in the plots which receive 40 Mg ha^{-1} of PL, is a robust indication about the improvement on soil quality in this area. However, the CMI values in all plots remained below 100 (Figure 1), showing that, even improving soil quality relative to the conditions after mining, *B. brizantha* cultivation with application of PL have not fully recovered the soil quality in this site after one year of reclamation process.

Grass yield

Was observed a significant (p<0.01) effect of the PL application on the grass yield (Figure 2). Moreover, the application of PL was associated with high grass biomass production in this area, with values above 15 Mg ha^{-1} (dry mass) for all doses. These results are a consequence of all the improvement on soil quality previously discussed. Animal manures are considered an excellent organic fertilizer, besides its effects on water retention and biological activity, among others indicators [16]. Because its effects on soil quality, animal manures have been used successfully during mined areas reclamation worldwide [8]. In quartzite mines in Brazil, the manure application showed a positive effect on the *B. brizantha* yield, with better results than inorganic fertilizers [27].

The main goal in soil reclamation must be to maximize SOM accretion by alleviating the most limiting factor for plant growth (usually N or P). Fertilization using high doses of PL showed good results enabling the experimental area to recover partially from degradation in the first year of reclamation process. The grass yielded 90% of its maximum productivity when 34 Mg ha^{-1} of PL was applied to the soil (Figure 2). Due to downhill slope (35% of gradient in the experimental areas), is mandatory to provide conditions to fast plant growth in these sites. In this sense, besides being an additional source of C, the PL has improved the soil quality, promoting the plant cover by B. brizantha, essential to soil C accretion and to control of erosion processes, the two main steps to successful land reclamation in bauxite-mined areas in Minas Gerais State, Brazil.

Conclusion

The stripping and stockpiling of topsoil notably decrease the soil fertility in bauxite-mined areas. Moreover, the CMI drastically decrease after mining. In this sense, a proper handling and storage of topsoil materials can decrease the loss of quality and foment the land reclamation process in these areas. Accordingly, only returning the topsoil may be not enough to reestablish the biomass production in these areas.

Poultry litter application presents a positive effect in emergent soil properties, such as N and P contents, cation exchange capacity and C management index. The application of high doses of poultry litter is associated with short-term improvements in soil quality, which yields to a high *B. Brizantha* biomass production, reaching 24 Mg ha^{-1} (dry mass) when soil was fertilized with 40 Mg ha^{-1} of poultry litter. Finally, we recommend the application of 34 Mg ha^{-1} of poultry litter in bauxite-mined areas in Minas Gerais State, Brazil.

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