Study of the chemical properties in mixtures of red mud with acidic savanna soil, and their effect on the growth of the species *Chrysopogon zizaniodes* (Vetiver)

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Summary

Red mud is a residual material formed during the process of extracting alumina from bauxite. In Venezuela, CVG Bauxilum Company generates around 1 million tons annually; these are accumulated in storage lagoons, due to its alkalinity (pH 10-13), salinity and content of toxic metals, represent a risk to the environment, that is why in the present investigation the red mud from CVG Bauxilum was used to neutralize acidic savanna soils, determining its influence on the chemical properties of the soil and its effect on the growth of the species *Chrysopogon zizanioides* (vetiver) a plant with phytoremediation properties. For the study, 9 trials were carried out with plants, three controls: acidic savanna soil (SAS), red mud neutralized with marine brines (LRN) and red mud without neutralization (LR), and six mixtures in three different proportions, which were 2%, 5% and 10% by mass of red mud (neutralized and without neutralization) applied to the soil; obtaining the most successful mixing ratios (based on vetiver development), were for neutralized red mud the mix of 2% (SLRN 3) and for red mud without neutralization also the mix of 2% (SLR 3). Chemical analyzes were performed on the subsamples collected from the SAS, LR, LRN, SLRN 3 and SLR 3 trials, at the beginning of the experiment, 48 days later and at the end; determining that the optimal proportion of mixture was SLRN 3, because it was the only one that had 100% survival of the plant during the 104 days of the experiment, the growth parameters indicate that it had greater development compared to the other trials, thanks to the contribution of the LRN, the pH increased from 5.01 to 7.41 (typical value in fertile soils), it also added elements such as Fe, Mg and K to the soil, essential nutrients for plants, and Al (toxic element to plants) remains retained in the substrate as a non-bioavailable phase.

Keywords: red mud, neutralization with marine brines, amendments, revegetation, vetiver, phytoremediation.

Introduction

More than 95% of the world's bauxite is refined by the Bayer process, using concentrated sodium hydroxide (NaOH) to dissolve the minerals present in the bauxitic ore, while the insoluble material is filtered and extracted from the alkaline solution obtained, and in turn are removed from the circuit in the hydrometallurgical process; this material is known as red mud. Alumina refineries generate significant volumes of waste (around 1 to 2 tons of red mud per ton of alumina produced) extremely alkaline (pH 10-13), saline and containing toxic metals, so its improper storage could generate serious environmental problems (Gupta and Ali, 2004; Lottermoser, 2010; Alshaal et al., 2013). It is for this reason that various uses have been proposed for red mud, such as applications in civil constructions and buildings, in the chemical industry as catalysts, raw material for the production of ceramics, coatings, pigments, metallurgical applications in the recovery of metals, environmental and agronomic applications in the amendment of contaminated and acidic soils, and neutralization of acid mining drains (Klauber et al., 2009).

Red mud due to its alkalinity makes it possible to amend sandy acid soils, increasing the pH and reducing the availability of toxic metals for plants such as cadmium and nickel, which improves soil fertility. The content of iron and aluminum oxides in red mud promotes phosphorus retention, and its fine texture promotes water retention in infertile sandy acid soils, its application can potentially reduce the eutrophication of nearby water bodies due to nutrient retention (Ho et al., 1989; Summers et al., 1996; Snars et al., 2003; Feigl et al., 2012). In order to use the red mud in revegetation plans, it is necessary to apply management strategies that reduce its toxicity (European Aluminium Association, 2013; Gautam and Agrawal 2017; Qi, 2021). One of these strategies is the partial neutralization with seawater and marine brines, that decreases the alkalinity and the concentration of dissolved metals in the residue, through the precipitation of oxides, hydroxides and carbonates of aluminum, magnesium and calcium (Paradis et al., 2007; Palmer and Frost, 2009).

One of the plants used in red mud revegetation plans has been vetiver (*Chrysopogon zizaniodes*), it is a grass with firm and erect stems, fast growing and which has proven to be appropriate for the conservation of soils and water, due to its contribution to the control of erosion, phytoremediation properties and absorption of toxic metals. Vetiver has a high range of adaptability to extreme conditions of temperature (-15ºC to 55ºC), pH (3.3 to 9.5); resists conditions of high salinity, concentrations of elements such as: aluminum (Al), manganese (Mn), arsenic (As) , cadmium (Cd), nickel (Ni), chromium (Cr), lead (Fe), mercury (Hg), selenium (Se) and zinc (Zn) in soils. Vetiver plantation is a natural and environmentally friendly solution, practical, simple and cost efficient (Orihuela, 2007; Truong et al., 2009; Gautam and Agrawal, 2017).

In Venezuela the company CVG Bauxilum, C.A. produces one million tons per year of red mud, which is accumulated in storage ponds. In recent years, researchers have been looking for options for recycling and reusing this environmental liability. In the present work red mud from the CVG Bauxilum Company was used to neutralize acidic savanna soils and improve the retention of water and nutrients in them, the fertility of the mixtures was evaluated by the growth of the species *Chrysopogon zizanioides*.

Materials and methods

Red mud samples and treatment

The red mud used in this work corresponded to two samples of approximately 15 kg each, these were taken by CVG Bauxilum personnel from the GEHO pump, where caustic liquor (liquid fraction) and red mud (solid fraction) coexist, and from lagoon 3C, which is the lagoon in where the red mud is dry.

The red mud from the GEHO pump was neutralized with marine brines in a ratio 4: 1 m/v (residue (g)/brines (mL)). After neutralization, the liquid fraction of the sample was separated by gravity, preserving the solid fraction that later it was put to dry in plastic trays at room temperature.

Acid savanna soil samples and treatment

To carry out the trials, were collected the first 15cm of an acid savanna sandy soil pH (5-5,2). Approximately 170 kg of soil were collected in an area near the CVG Bauxilum Company. Before mounting the tests, the soil sample was homogenized by quartering.

For simplification purposes, the neutralized red muds from the GEHO pump will be named as LRN, while the non-neutralized red muds from the lagoon 3C as LR, likewise the acidic savanna soil will be named as SAS.

The investigation included nine trials of approximately 3.7 kg each (figure 1), which were carried out in triplicate plus a control without plant, these were contained in plastic containers of around 4500 cm^3, with holes in the bottom to allow water to escape. The trials included the controls SAS, LRN, and LR, in addition to the mixtures of soils with neutralized red mud and with non-neutralized red mud in the proportions of 2%, 5% and 10% by mass; in each one a vetiver seedling was planted. These were watered daily from Monday to Friday with approximately 78 mL of distilled water since 07/30/2014 until 11/11/2014, to give a total of 104 days of the experiment. The amount of distilled water that was added to each trial was calculated according to the area of the plastic container 168 cm^2, trying to simulate the annual average rainfall for the region where the soil sample was collected, the average annual precipitation of the Bolívar state varies between 1026 mm in the northern and deltaic zone, and 2340 mm in the rest of the state according to Rodríguez et al. (2011).

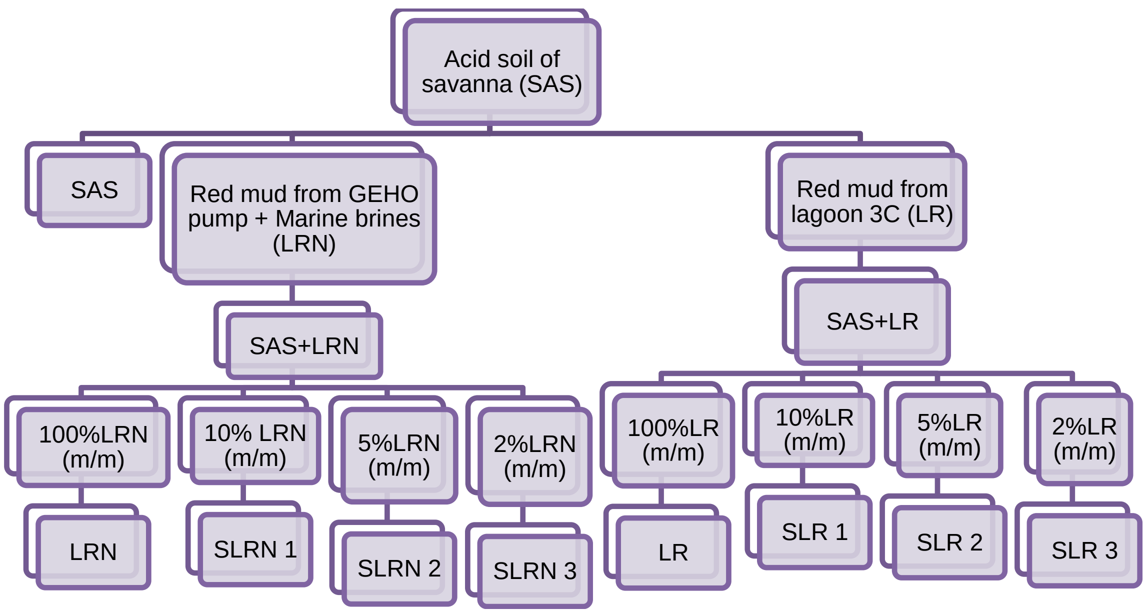


Figure 1. Experimental trials scheme.

Vetiver plants were supplied by Prof. Oscar Rodríguez from the Agronomy Faculty of the Central University of Venezuela in Maracay, Aragua state. 27 seedlings of the species were necessary for the elaboration of the trials. One month before sowing the plant in each trial, a previous rooting of the species was carried out in a sandy substrate (that is remove easily from the root), because the first month of plant growth is slow and no noticeable changes are observed in its growth, a condition that was necessary to evaluate its progress in the experiments.

Sampling of the trials and chemical analysis

To analyze the substrates over time, 6 subsamples of each trial were collected at three different times, before planting the plants (time 1), 48 days after sowing the plant (time 2) and 104 days (time 3) that was when the experiment ended. For this, a glass tube of 1 cm diameter and approximately 30 cm long was used, three random sampling points were selected in the trial, and two perforations were made at each point, obtaining a subsample of the first 12 cm of the substrate approximately.

Each sample was dried. The pH and electrical conductivity of the trial samples was measured in a ratio of 1: 2,5 mass (g)/volume (mL) of soil: distilled water, according to the method SW-846 9045 for soils of the US EPA (2000). The elemental composition of Al, Fe and Mg were determined by atomic absorption spectroscopy technique, and K was determined by atomic emission spectroscopy technique, using the PerkinElmer A. Analyst 200 Atomic Absorption Spectrometer equipment, for these a partial acid digestion was carried out, according to the method 3050b of the US EPA (1996), this method provides the extraction of elements that are mobile and available in the environment. The different mineralogical phases present in the trials were determined with the Philips X-ray Diffraction equipment equipped with a cobalt tube, using the powder method; to carry out this method, the samples were pulverized with the Fritsch Pulverisette Analysette Laborette equipment, until obtaining a fine and homogeneous powder.

Plant growth parameters

Each plant was taken with care and the roots were washed to remove substrate particles. To evaluate the fertility of the mixtures, the Chrysopogon zizaniodies (vetiver) was used; it was measured growth parameters such as: length of roots and leaves, number of new shoots and mass of the plant.

Results and discussion

Optimal mixing ratio of soil with red mud

The optimal mixing ratio of acidic savanna soil with red mud was chosen based on the growth and development of the vetiver plant. Obtaining at the end of the experiment (104 days later) 100% survival in the 2% mixing by mass of neutralized red mud with acidic savanna soil (SLRN 3). For the mixing by mass of red mud without neutralization (LR) with acidic savanna soil (SAS), even that none plant survived, the most successful mixture was the 2% (SLR 3), due to plants survived more time than in the trials of 5% and 10% mixing by mass (table 1).

Table 1. Survival time of the plants.

Sample	Survival time (days)
LRN 1, LRN 2, LRN 3	13
LR 1, LR 2, LR 3	26
SLR 1.1, SLR 1.2, SLR 1.3	26
SLR 2.1, SLR 2.2, SLR 2.3	44
SLR 3.1, SLR 3.2	44
SLR 3.3	65
SLRN 2.1	75
SLRN 2.2	79
SLRN 2.3	82
SAS 1, SAS 2,SAS 3	104
SLRN 3.1, SLRN 3.2, SLRN 3.3	104

Vetiver growth

The chemical analyses were made to the control samples (SAS, LR, and LRN) and the optimal mixing of red mud with acidic savanna soil (SLRN 3 and SLR 3). The only plants that survival were those of the trials SAS and SLRN 3; however they lost mass (table 2), because of the phytoremediation process of the vetiver that reduces the production of biomass due to the inhibition of respiration and several enzyme activities, which has a negative effect in some of the main physiological processes like photosynthesis (Antiochia et al., 2007; Gautam and Agrawal, 2017; Banerjee et al., 2019), to defend the external high concentration of metals, plants develop various strategies which include sequestration of metals, restriction of its uptake and transport to control the accumulation and translocation of toxic metals (Anjum et al., 2015; Banerjee et al., 2019).

During the experiment the plants of SAS and SLRN 3 trials has more new shoots and development of their leaves and roots. In the case of dead plants, those that belong to the SLR 3 trial showed more new shoots and development (table 2).

Table 2. Growth parameters determined in vetiver (*Chrysopogon zizanioides*).

Samples	Initial mass (±0,1 g)	Final mass (±0,1 g)	Percentage of mass loss (%)	Root length increase (±0,1 cm)	Leaves length increase (±0,1 cm)	New shoots
SAS 1	58,2	35,6	38,8±0,3	17,0	18,0	9
SAS 2	43,3	37,0	14,5±0,3	15,2	17,3	5
SAS 3	59,1	55,1	6,8±0,2	16,0	14,4	9
Interval			[6,8; 38,8]	[15,2; 17,0]	[14,4; 18,0]	[5, 9]
SLRN 3.1	39,5	34,2	13,4±0,4	25,0	16,5	10
SLRN 3.2	43,8	40,9	6,6±0,3	14,5	16,0	7
SLRN 3.3	45,8	36,2	21±0,3	14,1	13,0	5
Interval			[6,6; 21,0]	[14,1; 25,0]	[13,0; 16,5]	[5, 10]
SLR 3.1	53,4	29,2	45,3±0,3	3,5	14,5	3
SLR 3.2	47,6	31,0	34,9±0,3	4,3	9,8	4
SLR 3.3	56,0	31,6	43,6±0,3	4,7	7,0	5
Interval			[34,9; 45,3]	[3,5; 4,7]	[7,0; 14,5]	[3, 5]
LRN 1	42,1	22,6	46,3±0,4	1,5	0,5	2
LRN 2	35,2	16,8	52,3±0,4	2,0	-	3
LRN 3	37,8	20,0	47,1±0,4	1,0	0,6	1
Interval			[46,3; 52,3]	[1,0; 2,0]	[0,0; 0,6]	[1, 3]
LR 1	33,4	22,4	32,9±0,4	4,5	0,5	2
LR 2	33,3	23,6	29,1±0,4	3,5	0,5	4
LR 3	39,0	24,4	37,4±0,4	5	0,2	2
Interval			[29,1; 37,4]	[3,5; 5,0]	[0,2; 0,5]	[2, 4]

The plants of SLRN 3 trial showed an irregular morphology of their leaves and roots in comparison with the plants of SAS control trial. The SLRN 3 plants had a tendency to growth inclined, inferring that the content of LRN in these trials caused this irregularity in the plant growth (figure 2 and 3), coinciding wiht Gautam and Agrawal (2017) that in their phytoremediation work with red mud and vetiver, they observed that root-leaves lengths were strongly affected by accumulation of Cu, Cr, Pb, Mn and Zn in roots.

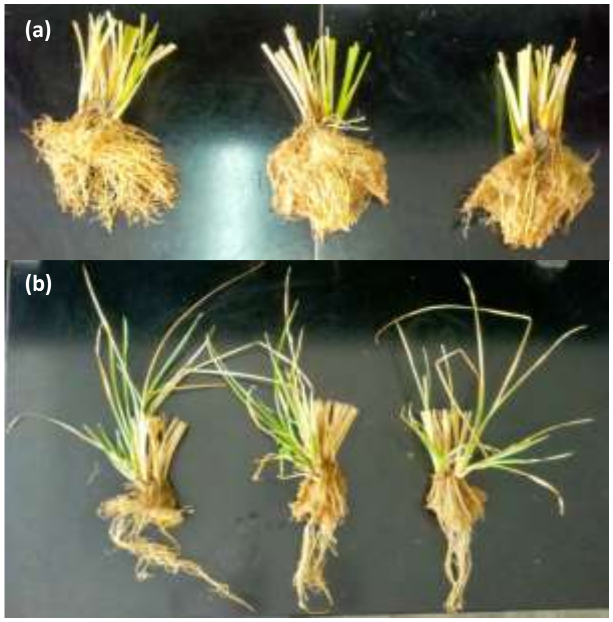


Figure 2. SLRN 3 trial plants (a) Time 1, (b) Time 3.

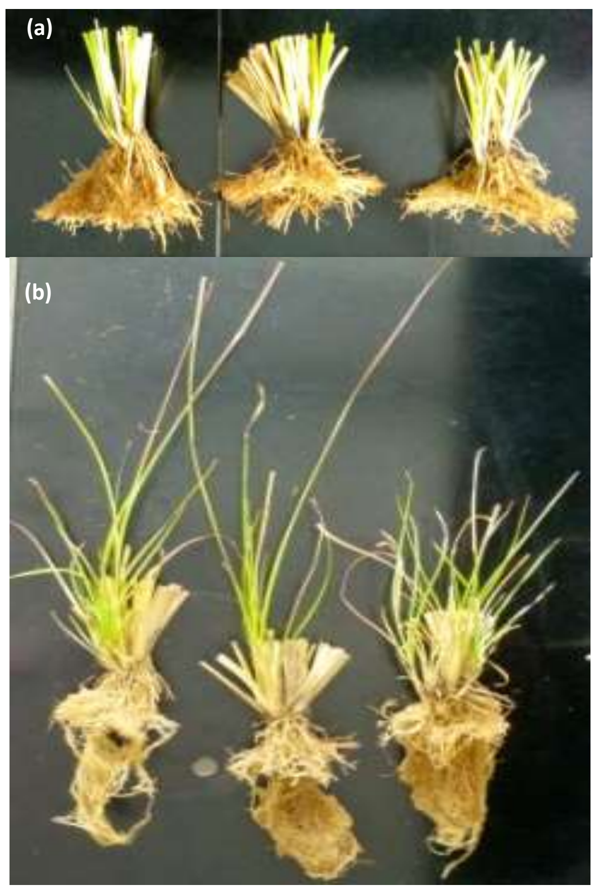


Figure 3. SAS control trial plants (a) Time 1, (b) Time 3.

The 2% mass of red mud as optimal mixing was a result expected, that concurred with the mixing ratio soil and red mud use in revegetation plans of researchers Summers et al. (1996), Summers et al. (2001), Doye and Duchesne (2002), Yi et al. (2006), Udeigwe et al. (2009) and Feigl et al. (2012).

Mineralogy

In the samples of the trials SAS, LRN and LR, the mineral phases detected by X-ray diffraction were the same over time. It was observed that in the mixtures (SLRN 3 and SLR 3), the mineral phase elucidated in the X-Ray spectrum, is quartz (SiO_2), the main mineralogical component of the soils, because the proportion of red mud in the mixtures is only 2% , the signals of the other mineral phases from the red mud are very low.

Red mud without neutralize (LR) was composed of quartz, gibbsite, hematite, anatase, sodalite, calcite and goethite as observed in table 3. Marine brines provide the red mud anions (Cl^-, SO_4^{2-} and CO_3^{2-}) and cations (Ca^{2+} and Mg^{2+} enriched, relative to the Na^+), that allowed the formation of new mineral phases such as halite, tychite and hydrotalcite (figure 4) coinciding with the results reported by Paradis (2007), Caccamo (2013), Marcano (2013) and Sarmiento (2013).

Table 3. Mineralogy of soil, red mud and mixtures.

Mineral phases	**Samples**				
	SLRN 3	SLR 3	SAS	LRN	LR
Quartz (SiO_2)	✓	✓	✓	✓	✓
Halite (NaCl)				✓	
Gibbsite ($Al(OH)_3$)				✓	✓
Hematite (Fe_2O_3)				✓	✓
Sodalite ($Na_4Si_3Al_3O_{12}Cl$)				✓	✓
Tychite ($Na_6Mg_2SO_4(CO_3)_4$)				✓	
Hydrotalcite ($Mg_6Al_2CO_3(OH)_{16}\cdot 4H_2O$)				✓	
Anatase (TiO_2)				✓	✓
Calcite ($CaCO_3$)					✓
Goethite (FeO(OH))				✓	✓

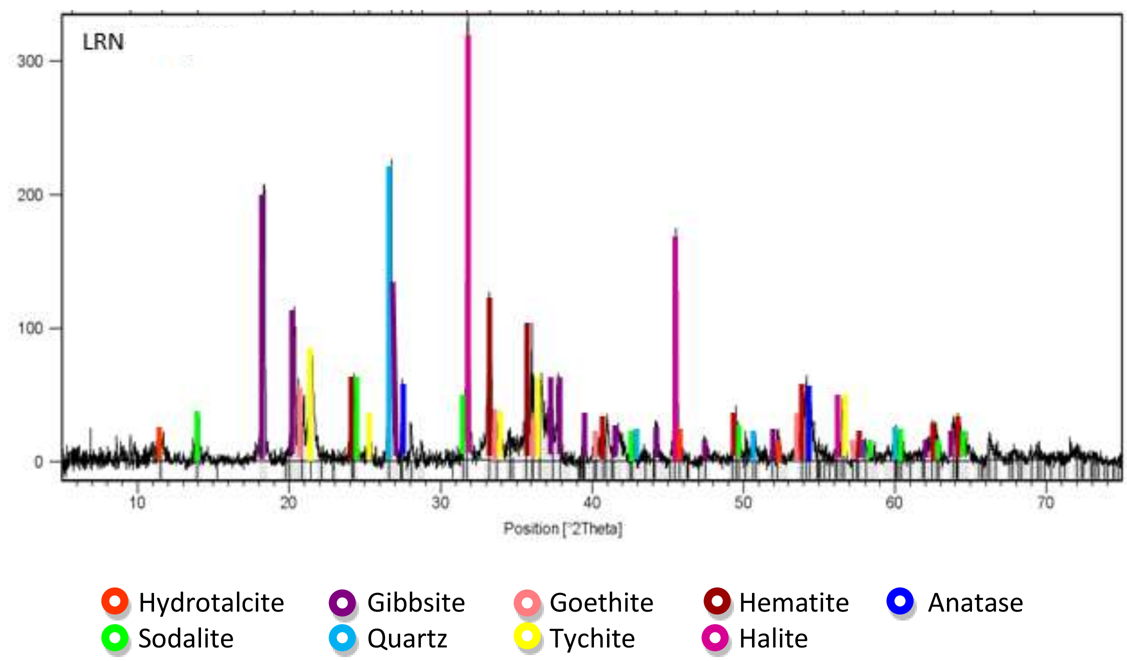


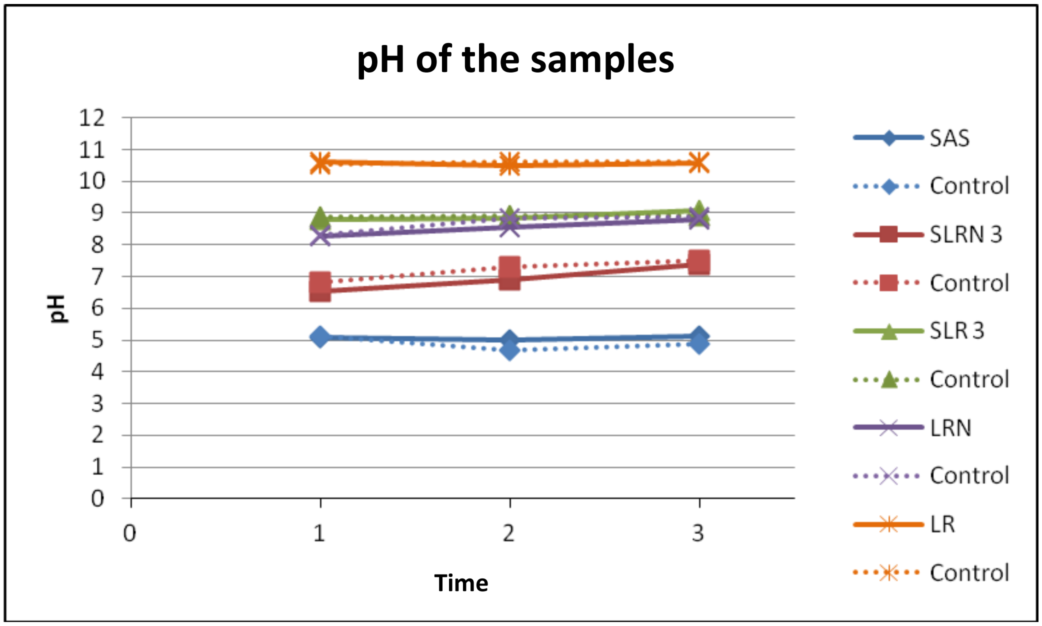
Figure 4. Diffractogram of the LRN sample

pH and electrical conductivity

The initial pH of the red mud collected from the GEHO pump was 13,03, after its neutralization with marine brines (4: 1 m/v ratio), separation by gravity of the solid fraction and dried, the pH of the resulting red mud was 8,29, a value that is within the allowed limits (6-9), according to Venezuelan environmental legislation (Gaceta Oficial Nº 5021, 1995), established to control the discharge of substances into the environment. Adding the neutralized red mud amendment to the acid soil of savanna resulted in a pH increase from 5,01 to 7,41 in the substrate, a value that is within environmentally permissible limits, and more importantly, it is a value commonly found in fertile soils.

In the case of the amendment with red mud without neutralizing from lagoon 3C pH 10.62; increased the soil pH to 9,10 at the end of the experiment. This value is contrary to that obtained when mixing neutralized red mud with acid soil in the same proportion, because it is at the limit of what is allowed by environmental regulations and from the point of view of fertility, although it is a value that can be found in some productive soils, the pH found in the mixture with neutralized red mud (SLRN 3) is much more desirable, since at neutral pH there is greater solubility of essential nutrients such as N, P, K, Ca and Mg that are absorbed by plants (Casanova, 2005).

In the graph 1 is observed that pH values in the SAS and SLRN 3 samples, they remain closer to neutrality with respect to their controls without plant, in both cases it seems that the plant has an effect on the pH of the substrate, this inference find support in the work done by Casanova (2005), who affirms that studies conducted with acidity-tolerant plant varieties can increase the pH in solutions, and that increase in pH is induced in the rhizosphere of the plant. In the present work, it was observed that for the SLR 3, LRN and LR samples there were no pH variations compared to their respective controls without a plant, it should be noted that the plants contained in these trials died during the development of the experiment, so they could not exert an effect on the substrate in which they were contained. This supports the thesis of the influence of vetiver plants on the pH found in soils.

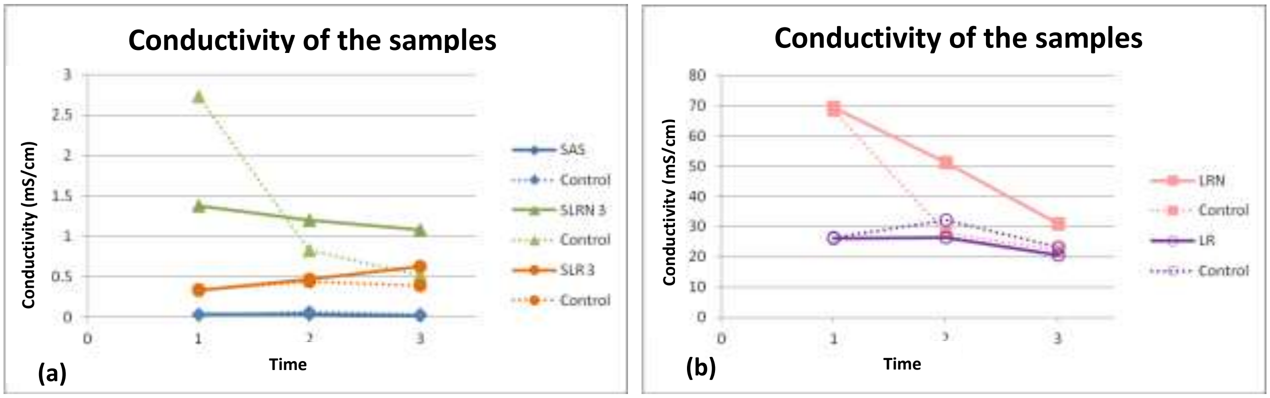


Graph 1. pH of soil, red mud and mixtures.

Regarding electrical conductivity values, at the end of the experiment (time 3), an increase of 0,020 mS/cm to 1,1 mS/cm occurred in the soil for the mixture with neutralized red mud (SLRN 3) y 0,6 mS/cm for the mixture with red mud without neutralization (SLR 3). SLRN 3 samples show a greater increase in conductivity due to marine brines that contribute a high concentration of soluble salts (halite) to the red mud during the neutralization process.

In graph 2(a) it is observed that for the sample SLRN 3 the conductivity gradually decreases over time, in contrast to the control without plant in which the conductivity has a much more pronounced decrease, this difference can be attributed to the action of the plant, the absorption of water by vetiver leads to a lower humidity of the substrate, so the rate of precipitation of salts would be higher in these cases. Additionally, according to the bibliography, depending on the supply of nutrients and pH, the plant roots tend to grow vertically in the soils, creating a large matrix with large surface area to take metals as well as nutrients from the substrate (Srivastava et al., 2008), allowing the retention of cations in the substrate by cation exchange processes.

The electrical conductivity values of the SAS, SLRN 3 and SLR 3 samples (graph 2(a)), according to the scale of tolerance of plants to salinity in Diagnosis and Improvement of Saline and Alkali Soils (1954), are founded within the range 0-2 mS/cm in which the effect of salinity is negligible on plants, and in the range 2-3 mS/cm affecting only the most sensitive crops. With this information it is possible to infer that SLR 3 electrical conductivity did not negatively affect the development of the plant. In the case of LR and LRN samples (graph 2(b)), its conductivity values fall in the extreme salinity range, over 16 mS/cm, in which only a few resistant plants can develop, is indicating that salinity was one of the causes of the inhibition in the growth of vetiver for these trials.

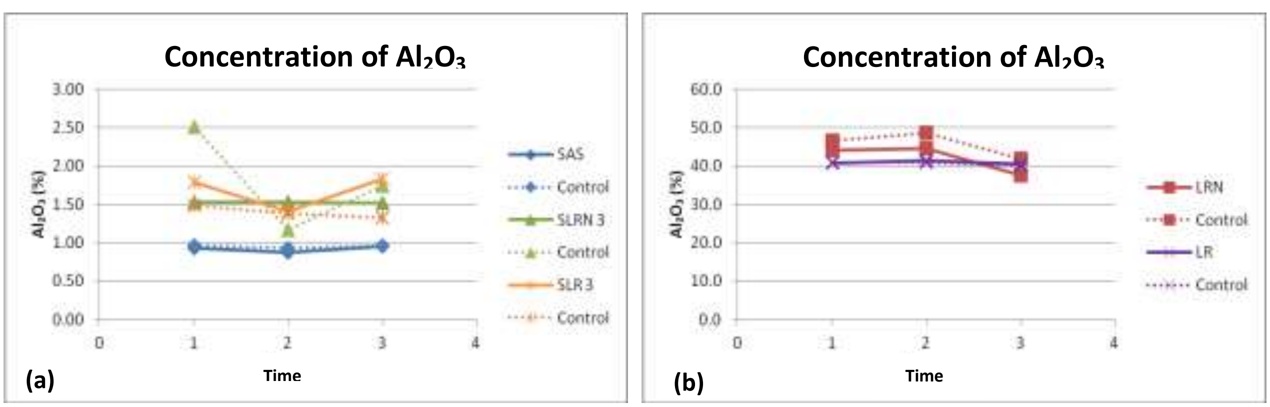


Graph 2. Electrical conductivity of soil, red mud and mixtures.

Elemental composition (Al, Fe, Mg and K)

SAS sample possess the lowest concentration of Al, 0,96% at the end of the experiment (graph 3(a)), probably contained in hydroxyaluminosilicates that were not elucidated by X-Ray because of their concentration. LRN and LR samples were those with highest concentration of Al between 40 and 50% (graph 3(b)), the main source of this element in LR was gibbsite, in the case of LRN it is also found in hydrotalcite. Gibbsite is a very insoluble mineral (K_{ps}= 3_x10^{-34}) and is kinetically an inert phase (Exley et al., 2002) at pH between 4 and 8,5. Al is very sensitive to pH variations, in LR Al remained unchanged over time as did pH; on the other hand, in the LRN it had a tendency to decrease over time, contrary to what happened with pH, as the pH increases, above 8,5 Al is soluble as AlO^{2-} so its concentration in the substrate decreased. For the mixtures SLRN 3 and SLR 3 (graph 3(a)) Al did not follow a clear trend.

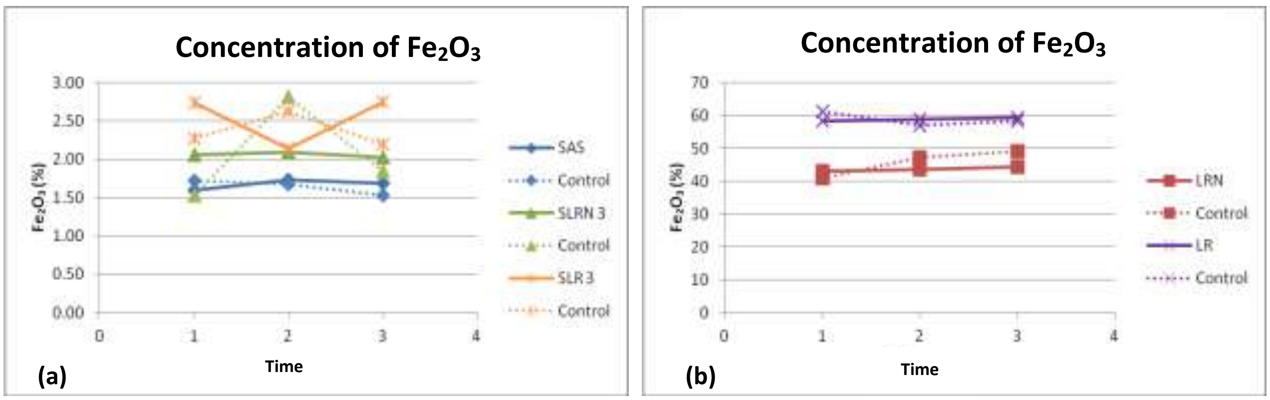
The application of neutralized red mud in a proportion of 2% for the amendment of acidic savanna soil, it was favorable because it allowed to keep the aluminum in a non-bioavailable form thanks to the maintained neutrality in the soil, this was one of the factors that favored the growth of vetiver; contrary to what happened with SLR 3, at this pH, Al is a bioavailable species, and in sufficient concentration to be toxic to plants, being one of the reasons why they did not survive.



Graph 3. Al concentration expressed as oxide in soil, red mud and mixtures.

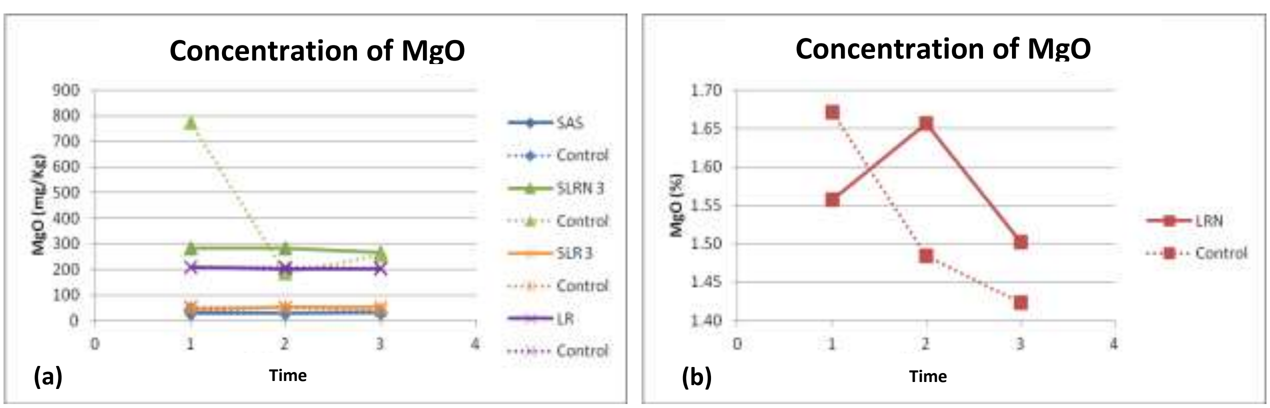
Fe in the samples was contained in mineral phases such as goethite and hematite, which are very stable in alkaline conditions (pH greater than 9) (McCafferty, 2010). SAS samples showed an invariant Fe concentration over time (graph 4(a)), it was found as an inert (insoluble) species. For the SLRN 3 and SLR 3 samples, the Fe concentration did not show a clear trend (graph 4(a)) as for Al.

LR had about 10% more Fe compared to LRN (graph 4(b)), this difference is due to the pH of the substrate, in the case of LR it was approximately 10,5 pH that corresponds to the stability zone of Fe; a condition that did not occur for the LRN samples, because at a pH lower than 9, Fe is soluble in aqueous solutions.



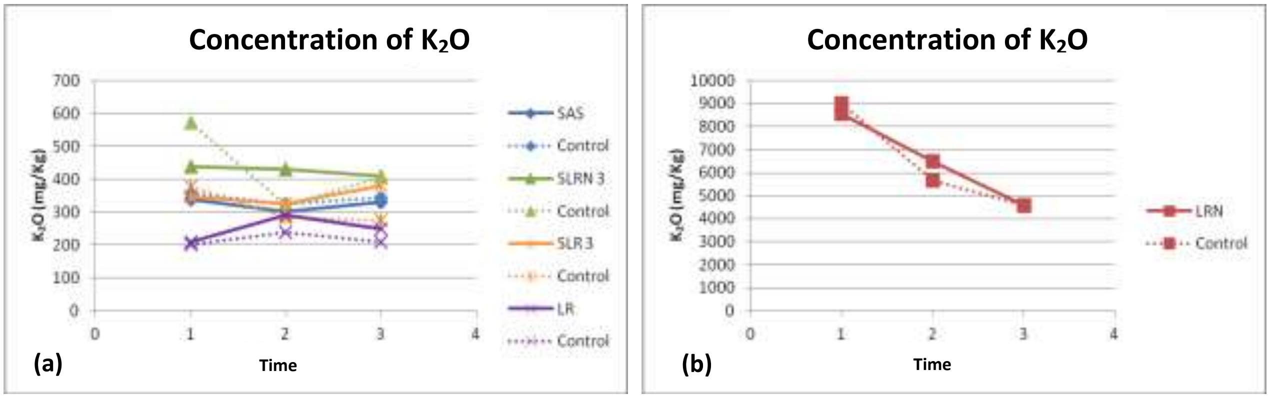
Graph 4. Fe concentration expressed as oxide in soil, red mud and mixtures.

Marine brines were the main source of Mg in samples LRN and SLRN 3 (graph 5(a) and 5(b)), being retained in these substrates by the precipitation of new mineral phases: tychite and hydrotalcite, formed during neutralization of red mud with marine brines. In the case of SLRN 3, the concentration of Mg (230- 350 mg/Kg) (graph 5(a)) is within the tolerance limit of vetiver which is 2400 mg/Kg, according to Truong et al. (2009); neutralization of red mud with marine brines provides Mg, a source of nutrients for the plants, inferring that this was one of the factors that allowed the development and survival of vetiver. SAS, SLR 3 and LR did not have any significant source of Mg, being reflected in the concentration it has in these substrates.



Graph 5. Mg concentration expressed as oxide in soil, red mud and mixtures.

Marine brines provide K to the soil, which is why SLRN 3 and LRN (graph 6(a) and 6(b)) were the ones with the highest concentration of K. For SLRN 3 the concentration of K remains constant over time, in comparison with its control without plant, the plant exert an effect on the substrate, since vetiver, thanks to its detoxifying mechanisms of the soil, can absorb toxic metals (Srivastava et al., 2008), leaving free cation exchange spaces allowing K to remain retained. In LRN samples, K decreases over time, because it was leached from the substrate since there is no possibility of absorption by the plants as they died.



Graph 6. K concentration expressed as oxide in soil, red mud and mixtures.

Conclusions

In the present study, it was obtained that the optimal proportion of mixing was 2% by mass of red mud neutralized with acidic savanna soil (SLRN 3), at the end of the experiment 100% of the vetiver plant survived. Parameters growth (mass, length of leaves and roots, and new shoots) measured in the plant indicate that they had greater development compared to the other trials. The loss of biomass in the surviving plants was attributed to the high concentration of metals and phytoremediation processes, coinciding with what was observed in the plants morphology of SLRN 3 trials, their roots and leaves were irregular because of LRN content in the substrate. In addition, the chemical analyzes of the substrate show evidence that the plant exerts an effect on the substrate.

The neutralization of the red mud from the GEHO pump with marine brines in the proportion 4 g of red mud/1 mL of marine brines generates the formation of new mineral phases such as halite (NaCl), tychite ($Na_6Mg_2SO_4(CO_3)_4$)) and hydrotalcite ($Mg_6Al_2CO_3(OH)_{16} \cdot 4H_2O$), which lowers the pH of the red mud from 13,03 to 8,29, this value being within the environmentally permitted limits for the discharge of substances into the environment. With the application of 2% neutralized red mud (LRN) to the soils (SAS), the pH increased from 5,01 to 7,41, a pH value close to fertile soils; electrical conductivity increased too, from 0,020 mS/cm to 1,1 mS/cm in the SLRN 3 sample and to 0,6 mS/cm for the SLR 3 sample, these values indicate that the conductivity did not have a negative effect on the development of vetiver, according to scale of tolerance of plants to salinity.

In the trials SLRN 3, the content of LRN allowed the retention of aluminum in the substrate as a non-bioavailable species, insoluble under the pH conditions of the substrate, it was a key factor that favored plant growth. Contrary to what happened with the SLR 3 samples, in those Al was a bioavailable species due to the pH of the substrate, being one of the reasons why the plants did not survive. LRN also supplied the substrate with nutrients such as Fe, Mg and K, an essential nutrient for plants, which is a key factor in the remediation of the soil and the revegetation plan.

Observations

In the search for the most complete compression of the systems, it is convenient to determine the concentration of metals such as Mn, Zn, Cu, Mo, Co, Cd, Pb, Cr, Ti and Ni, both in the substrate and in its leachate.

In order to evaluate the effect that the plant had on the studied substrates, it is recommended to carry out a chemical analysis of its roots and leaves.

It is recommended to carry out a trial on a larger scale and for a longer time with the mixing ratio established as optimal with application of fertilizer, to evaluate its influence on the physical and chemical properties of the soil and on the plant in the long term.

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