

Use of vinasse and biocarbon to the remediation of saline - sodium soils in the district of Tambogrande, Piura

Freddy Manyari^a, Jhonny Valverde Flores^{a, b,*}

^aDepartment of Environmental engineering, University Cesar Vallejo – Lima Norte, C.P. 15314, Lima 39, Peru.

^bInstitute of Environment, Centre of Research and Training to the Regional Development (CINCADER). Lima 39, Peru.

jhoval1@yahoo.es

Resumen

La vinaza y el biocarbón se utilizan como recuperadores de suelos salino-sódicos. El objetivo fue analizar el proceso de remediación de suelos salino-sódicos en el distrito de Tambo Grande, Piura. Se utilizó una muestra de 10 kg de suelo salino el cual fue llevado al laboratorio para comprobación. Se construyeron dos columnas de suelo; en el extremo inferior de cada columna se colocó un recipiente colector de lixiviados. Las columnas se dividieron en dos tratamientos: la primera, un tratamiento con agua y la segunda, un tratamiento con vinaza; se simularon las condiciones del lavado en campo para cada columna, periódicamente se analizaron los lixiviados y al finalizar un mes de tratamiento se realizó el análisis de cada uno de los suelos en las columnas. Los resultados finales indicaron una disminución en el PSI (0.49), en la concentración de sodio (3.52 meq/L), Conductividad Eléctrica (1.46 dS/m), así como un aumento de nutrientes principalmente potasio (20 meq/L) y porcentaje de materia orgánica (2.17%). Para evaluar la efectividad del suelo se realizaron pruebas en macetas con un cultivo llamado rabanito (*Raphanus sativus*) en cuatro macetas de las cuales una era muestra en blanco (sin ningún tipo de tratamiento) y las tres restantes tenían el suelo tratado con vinaza con distintas proporciones de biocarbón (25%, 50% 75% en peso), para ello se tomaron como parámetros el crecimiento (cm) y el vigor (número de hojas, número de brotes) del cultivo. Los resultados indicaron un mejor crecimiento en el tratamiento con el 25% de biocarbón, asimismo se evidenció la falta de crecimiento en el tratamiento testigo.

Palabras clave: vinaza, biocarbón, PSI, Conductividad Eléctrica.

Abstract

Vinasse and biocarbon are used as recuperators of saline-sodium soils. The objective was to analyze remediation process of saline-sodium soils in the district of Tambo Grande, Piura. A sample of 10 kg of saline soil was used and it was taken to the laboratory for testing. Two columns of ground were built; at the lower end of each column was placed a leachate collecting vessel. The columns were divided into two treatments: the first was treated with water and the second was treated with vinasse; the conditions of the field washing were simulated for each column, periodically the leachates were analyzed and at the end of one month of treatment was performed analysis each of the soils in the columns. The final results indicated a decrease PSI (0.49), sodium (3.52 meq/L), Electrical Conductivity (1.46 dS/m), as well as an increase of nutrients mainly potassium (20 meq/L) and percentage of organic matter (2.17%). To evaluate the effectiveness of the soil, tests were carried out in pots with a culture called wild radish (*raphanus sativus*) in four pots of which one was a blank sample (without any treatment) and the remaining three had the soil treated with vinasse with different proportions of (25%, 50%, 75% by weight), for which the growth (cm) and vigor (number of leaves, number of shoots) of the crop were taken as parameters. The results indicated a better growth in the treatment with 25% of biochar, also evidenced the lack of growth in the control treatment.

Keywords: vinasse, biochar, PSI, Electrical conductivity.

1. Introduction

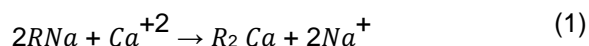
There are many alternatives to solving the problem of saline soils. In the present work two main and novel methods are presented: first; vinasse that removes excess salts, provides essential nutrients in the soil, increases the amount of organic matter and improves soil texture; and second, the use of biocarbon, which acts as an excellent enhancer that increases the capacity of retention of water and nutrients. The use of these two treatments together improves the physical, chemical and biological quality of the soil improving the yield in the growth of the plants.

Saline soils may be of natural origin (primary salinity) or of anthropogenic origin (secondary salinity). When salinity is of the natural type, two types of accumulation are distinguished: continental salinity and marine salinity (...) Secondary salinity is mainly caused by ignorance or misuse of management practices, both soil and water irrigation, overexploitation of aquifers, agricultural and industrial activity. (Hernández, 2000)

The Vinasse

Vinasse is a by-product of alcohol manufacture that is produced in a ratio of 13: 1; that is to say, for each liter of alcohol 13 liters of vinasse is obtained. Vinasse, resulting from the distillation of fermented molasses, has an interesting elemental composition and contains all the components of the wine that have been entrained by water vapor, as well as amounts of residual sugar and volatile components. The components that can be found in vinasse are: inorganic substances with a predominance of Ca^{+2} , K^+ and SO_4^{-2} ions, yeast cells, organic substances resulting from the metabolic processes of yeast, insoluble organic substances, volatile organic substances, alcohol and residual sugar (Herrada, 2009).

The application of vinasse stimulates the growth of soil microbiota. (Gasca, 2010). Hydraulic conductivity and vinasse concentration in degrees Brix ($^{\circ}\text{Brix}$) have an inverse proportional effect. From this it can be concluded that an increase in the concentration of vinasse prevents the passage of fluids through the soil. (Rojas et al., 2008). Vinaza; reacts with the calcium producing greater solubility in the water, besides the acids that contain a chelating character make it very suitable for acid and basic soils. In the case of a sodium soil, the vinasse acts as an ion exchange complex by displacing the sodium which is subsequently washed. (Rosas, 2010). Vinasse acts as recovering agent basically due to its high electrolytic power with high concentrations of Ca^{2+} and Mg^{2+} ions to understand the process it is necessary to explain the operation of the ion exchange resins used in water softening and then compare it with the produced effect on the floor. (Rojas, 2005). Its function is to exchange ions between a solid and a liquid without changes in the structure of the solid. The solid has attached to its surface a large number of ionizable atoms. Hard water with high concentrations of Ca^{2+} and Mg^{2+} ions enters the exchange column. The resin initially has Na^+ ions attached, when the exchange initiates some ions of calcium and magnesium are adsorbed by the resin and the sodium ions are released. Calcium is a divalent cation (it has 2 extra protons in the atom) as opposed to sodium which is a monovalent cation (only has an extra proton) and because of the same charge, they repel; therefore, two sodium ions are displaced by each magnesium ion or calcium.



Then the sodium ions are depleted in the resin which is replaced by calcium and magnesium ions, the water is now softened as it contains no ions responsible for the hardness of water.

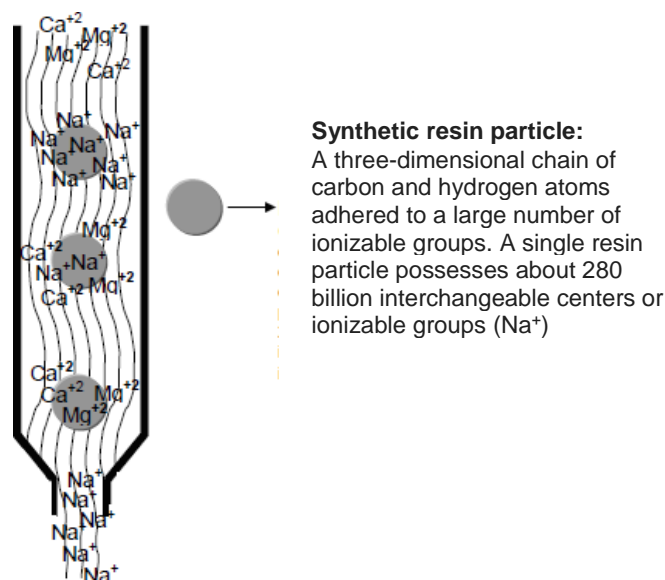


Figure 1. Scheme of Ion Exchange Column
Source: Rojas (2005)

Biocarbon

Biocarbon is a porous, carbonaceous solid material produced by pyrolysis of organic materials in an oxygen-depleted or depleted environment, which gives it physical-chemical properties that make it suitable for the safe and long-term storage of carbon in a natural environment and potentially improve soil fertility (Ibarrola, 2013). Biocarbon contains low salt content (C.E = 0.7), a mainly basic pH (pH = 9.4) and low content of nutrients such as potassium, phosphorus, calcium, magnesium, potassium and sulfur, generally not exceeding 1%. (Pérez et al., 2013). Biocarbon increases the growth of plants such as tomatoes by 10%, increases the dry weight of plants by 35%, and reduces 49% of insects found in 7 weeks. (Henreaux, 2012).

Biochar can be obtained from various materials that will determine the physicochemical characteristics of the biochar produced. Also the conditions of the pyrolysis process can generate biochars with different characteristics even starting from the same material. In general, increasing the temperature of the pyrolysis process decreases the yield of biocarbon but has a higher surface area and more stability. Among other characteristics of the biochar, it is important to highlight the presence of nutrients such as K, P, Ca, S, Mg, etc. and an alkaline pH in addition to a high porosity that gives it the possibility to retain water and nutrients for longer (Olmo, 2016). The use of bio-carbon in the soil reduces the leaching of nutrients, so it may be beneficial to avoid contamination of groundwater by fertilizers (Major, 2006).

Pyrolytic techniques for the production of biocarbon are: Pyrolysis slow (uniform and slow heating during days at temperatures between 450 and 650 °C), Rapid Pyrolysis (lasts one or two seconds at moderate temperatures of 450 °C), Gasification (syngas obtained at high temperatures between 800 °C and 1300 °C) (Paco, 2012).

2. Materials and Methods

The type of research is applied, the level of research is explanatory. The research design is quasi-experimental. The population is one hectare (1ha) of soil contaminated with salinity in the territories of Tambo Grande, Piura, Peru.

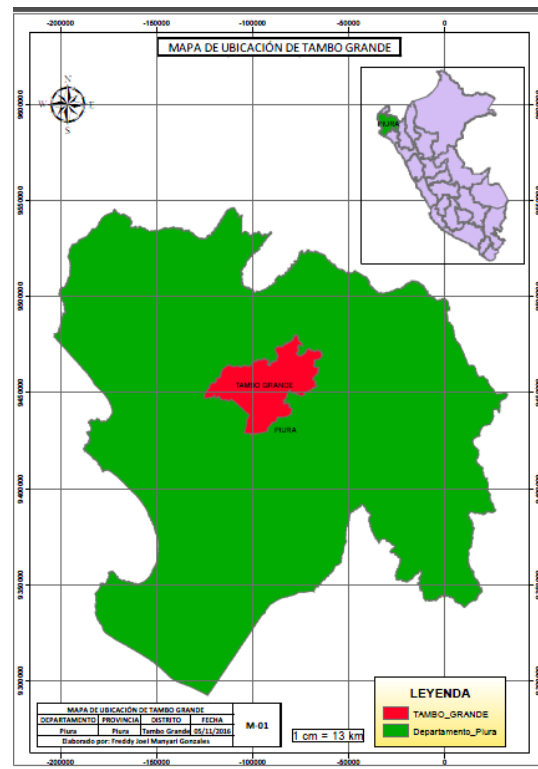


Figure 2. Map of the district of Tambo Grande, Piura

The total sample was 10 kg of saline-sodium soil in an area of 625 m² affected by salinity; 10 sampling points were taken (composite sampling) in which the simple random sampling type was applied, which is considered the most appropriate due to the homogeneous characteristics of the land under investigation.

For sampling was chosen to use simple random sampling with heterogeneous distribution with the zig-zag form, because the study area presents a uniform, homogeneous contamination and in its extension does not exceed 5 hectares, each sample was packed inside two PVC columns.

Stages

- Collection of information from the affected area. Observation of the physical characteristics of the soil (texture, humidity, color, etc.)
- Determination of the area of study. Measurement of the affected area
- Obtaining the soil sample. Compound zig-zag sampling
- Application of soil treatment. Experimentation
- Analysis of leachate. Determination of sodium concentration (Na⁺) and Electrical Conductivity (C.E)

Preparation of columns

In columns of PVC of diameter 10.16 cm and length 1 m previously homogenized soil was packed, the height chosen to pack the soil is based on the criteria of the Handbook N° 60 of the agriculture department of the United States, in this case was worked with 40 cm of packed soil to be recovered, at the lower end of the tube was added a collecting vessel for leaching.

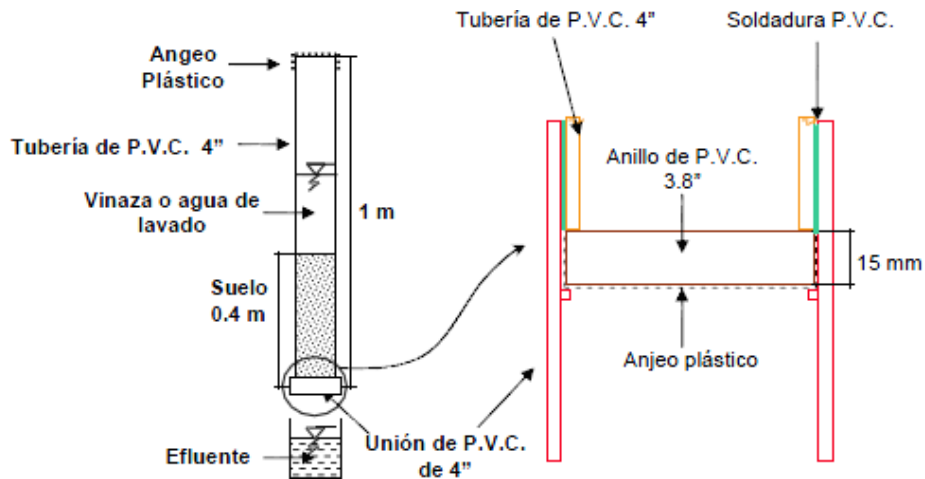


Figure 3. Outline of PVC pipe's design
Source: Adapted from Rojas (2005)

It is important to emphasize that in order for the vinasse to pass more easily through the soil layers must be added dose of vinasse and water. When reconstituted vinasse crosses the soil, a volume of washing with water is applied to simulate the natural conditions of soil washing. The volume of percolated liquid is collected in a vessel and analyzed in a laboratory. The data of the analysis of both soil and leachate are recorded in the respective sheets.

Obtaining the vinasse

Vinasse is a residual effluent from alcohol production that occurs in sugar cane processing as explained in the following scheme:

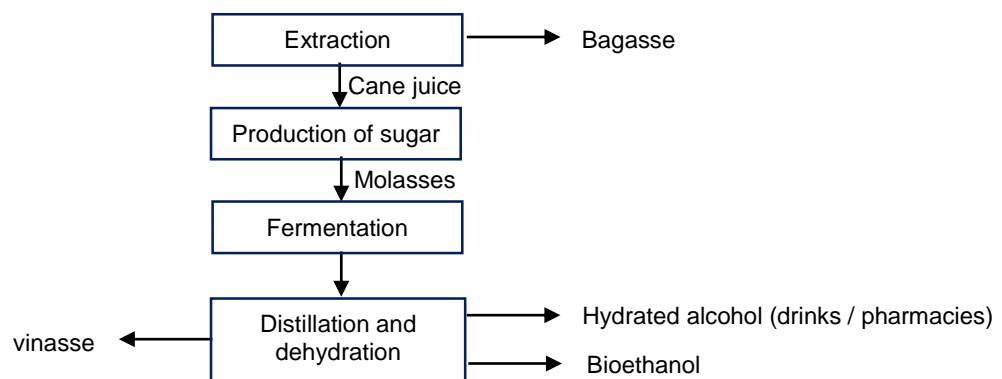


Figure 4. Scheme of the process of obtaining the vinasse

Obtaining the biocarbon

The production of biocarbon is given by the total or partially anaerobic combustion (pyrolysis) of any type of natural biomass; is produced by means of kilns in which the biomass is stacked, for example branches and leaves at a temperature of approximately 450 °C with little or no oxygen. At present, the industrial production of bio-carbon, is destined to the production of synthetic gas and biofuels, since they can control the temperature and the characteristics of the biomass used.

Biocarbon treatment

In order to verify the effectiveness of the treatment in the soil, after the treated soil with vinasse, is added biochar in different percentages (25%, 50% and 75%) having in total 3 treatments and a control using a crop called wild radish (*Raphanus sativus*) as indicator to measure the growth parameter (height in centimeters) and vigor expressed in number of leaves and number of shoots.



Figure 5. Treatments called blank, A, B, and C.

3. Results

Vinasse Analysis

Vinasse is a liquid of viscous nature, brown color, resulting from the sugar processing. The results of the vinasse analysis show a moderate degree of acidity (pH = 4.25) with high concentration of elements such as nitrogen (1279.6 mg / L), potassium (2375 mg / L), calcium (942 mg / L) and others . In the case of organic matter in solution, a high quantity (M.O = 37.71 g / L) is also present due to the presence of microorganisms characteristic of the fermentation (mainly yeasts).

Table 1. Chemical Composition of Vinasse Analyzed in Laboratory

Parameters	Value
pH	4.25
E.C. (dS/m)	28.1
Total Solids (g/L)	65.82
organic matter in solution (g/L)	37.71
N total (mg/L)	1279.6
P total (mg/L)	63.51
K total (mg/L)	2375
Ca total (mg/L)	942
Mg total (mg/L)	830
Na total (mg/L)	510

Soil analysis

Before doing the treatments in the columns, the soil sampled was taken to analyze in a certified laboratory. To make it easier to read results, the types of soil sampled were divided into three: Soil without Treatment (ST), Soil treatment with Water (SW) and Soil treatment with vinasse (SV). The following codes were assigned to the leachate results: Water leachate (WL) and leachate from the column with vinasse (LV). The results of the treatment are shown below:

Table 2. Parameters of the physicochemical characteristics of soils without/with treatment

Parameters	Soil without treatment (pre treatment)	Soil with treatment			
		With water		With vinasse	
		Values	Percentage Variation	Values	Percentage Variation
Na ⁺ (meq/L)	343.48	21.74	-93.7%	3.52	-99.0%
CIC	13.92	17.92	28.7%	16.00	14.9%
EC (dS/m)	16.04	0.64	-96.0%	1.46	-90.9%
O.M (%)	0.36	1.23	241.7%	2.17	502.8%
pH	7.82	8.36	6.9%	8.04	2.8%
PSI	9	10.92	21.3%	0.49	-94.6%
K ⁺ (meq/L)	1.95	0.39	-80.0%	20	925.6%
Ca ²⁺ (meq/L)	146.5	3.74	-97.4%	17.25	-88.2%

Sodium concentration

This result initially shows a high pre-treatment sodium content (343.48 meq/L), which was reduced to a minimum of 3.52 meq/L for treatment with vinasse.

Cation Exchange Capacity (CEC)

The cation exchange capacity (CEC), which establishes the ion exchange positions in the soil particles, determines the amount of displaceable cations, and its value depends on the amount of organic matter it possesses; the greater the amount of organic matter it contains, the less leaching of cations will increase its CEC, and can observe since in a soil with low amount of organic matter in is no water supply, its CEC remains constant (13.92); therefore, the greater the contribution of cations and organic matter, the higher the CEC as shown in both the treatment with water (17.92) and the treatment with vinasse (16.00).

Electrical Conductivity (EC)

The electrical conductivity is related to the CIC, but in this case refers to the amount of dissolved ions in the liquid phase of the soil. In case of the soil without treatment the electrical conductivity rose to 16.04 dS/m, so it is classified as an extremely saline soil, however by means of the two types of treatments it was reduced to 0.64 for SW and 1.46 dS/m for SV.

Percentage of Organic Matter (% OM)

Due to the high content of organic matter, microorganisms used in the sugar processing process (mesophiles and thermophiles), mainly yeasts for the production of ethanol (*Saccharomyces cerevisiae*); which when it is added to the soil and in the absence of oxygen, are multiplied by increasing the percentage of organic matter in the soil. Before the treatment the soil was low in organic matter (0.36%), but with the treatment with vinasse in a period of 1 month it was possible to increase to 2.17%.

Soil pH

To understand the behavior of pH in the soil it is necessary to know a term called ionization of the functional groups. On the surface of the solid part of the soils there are functional groups such as hydroxyl, carboxyl, phenol and amino groups. The load that depends on the pH of the soil solution. In general for an acid medium

these functional groups will tend to gain protons (H⁺) and charge positively; while for alkaline media it will tend to be negatively charged.



Vinasse is a product with a strongly acidic pH, so when applied to the soil it initially modifies its pH. However the soil acts as a buffer, stabilizing the pH of the soil, which is why a slight increase in pH is observed in the treatment with vinasse (pH = 8.04).

Percentage of Interchangeable Sodium (PIS)

It is another parameter that serve to measure the salinity in the soils and is related to the concentration of exchangeable sodium in the soil. The cation exchange capacity (CEC), defined as the ratio of sodium concentration to cation exchange capacity of a soil, shows that the soil is slightly saline in the soil without treatment (9%) and that due to the removal of sodium with the use of vinasse PSI decreases up to 0.49%, classifying it as non-sodium.

Potassium Concentration (K⁺)

A high amount of potassium (2375 mg/L) added to the soil increased the initial concentration of 1.95 meq/L but at the end of the treatment with vinasse rose to 20 meq/L, potassium (K⁺) constitutes one of the most important macronutrients in the plants development.

Calcium concentration (Ca⁺²)

Soils with water treatment and vinasse treatment showed significant differences with respect to the soil without treatment (Ca²⁺ = 146 meq/L). Soil initially had a high concentration of calcium, adding the vinasse, which contains a high amount of calcium (942 mg/L) displaced the soluble calcium cations present in the soil, decreasing its concentration to 17.25 meq/L. In the case of water treatment the process occurred by leaching and salts washing.

Analysis of leachate

Sodium concentration and electrical conductivity in leachate

For leachate analysis along the treatment, leachates from each soil column were divided and assigned codes: water leachate (WL) and leachate with vinasse (LV). The following are the results of the leachates:

Table 3. Sodium content and electrical conductivity of leachate according to treatment.

Repetitions	Sodium content Na ⁺ (ppm)		Electrical Conductivity EC (dS/m)	
	Treatment		Treatment	
	With water	With vinasse	With water	With vinasse
1	27700	11600	42.6	21.9
2	355000	49.5	2.85	5.02
3		280000		1.04

The initial composition of soil leachates with vinasse indicated a high concentration of sodium (27,700 ppm) and electrical conductivity (42.60 dS/m) for soils treatment with water. In the case of sodium concentration over time an increase is observed up to 355000 ppm, therefore a strong initial leaching of sodium removed in this column is demonstrated. This is supported both by the reduction of the electrical conductivity up to 2.85 dS/m, so that having such a small amount was chosen to stop the experiment.

For the soils of the vinasse treatment the results also showed a high concentration of sodium (11600 ppm) and electrical conductivity (21.9 dS/m), the concentration of sodium in the leachates of the treatment with vinasse increased to 280000 ppm, reason why as in the previous case this is reflected in the electrical conductivity. It can also be observed that the last analysis had a better removal result. It was the leachate

of the treatment with vinasse (1.04 dS/m). These results show that there has been salts deposited in the bottom of the column.

Subsequently, once the treatment was finished, a comparison was made of both the volume of the leachates and their coloration.

Table 4. Summary table of leachate application

Soil	Days	Volumes of water		
		Applied vinasse (mL)	Applied water (mL)	Leachate volumes (mL)
SV	Initial day	300	1000	1250
	1 st day	300	1000	1230
	5 th day	300	1000	1000
	10 th day	300	1000	1150
	12 th day	300	1000	1100
SW	Initial day	-	2000	1250
	5 th day	-	2000	1130
	10 th day	-	2000	1175

Note:
SV: Soils with application of vinasse
SW: Soils with water application

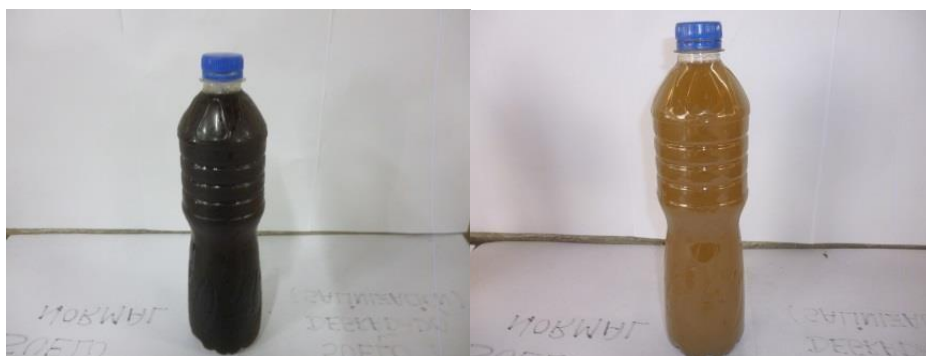


Figure 6. Changes of coloration in soil leachates with vinasse throughout the treatment (left to right)

Coloration with time gradually clear up. However, the time interval at which the representative sample of leachates could be obtained for analysis was increasing.

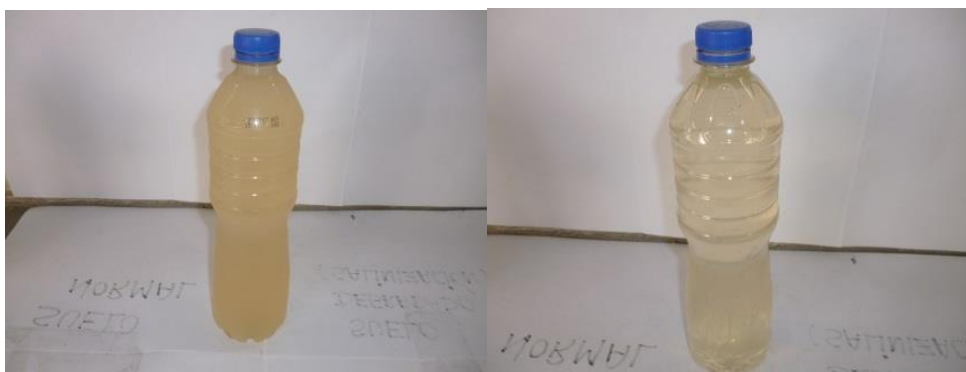


Figure 7. Changes of coloration before and after in soil leachates with vinasse (left to right)

Growth of the crop with the use of biochar

Plants of wild radish growth were measured with different amounts of biochar mixed and blank. The pots were subjected to the same weather conditions and amount of seeds were added.

Table 5. Summary of the growth of the wild radish crop

crop		Measurement cultivation			
		N° planted seeds	N° germinated seeds	N° leaves	N° height (cm)
blank	1 st week	6	2	4	4
	2 nd week	6	2	8	7
	3 th week	6	2	11	9
A (75%V 25%BC)	1 st week	6	6	18	7
	2 nd week	6	6	37	9
	3 th week	6	6	45	11
B (50%V 50%BC)	1 st week	6	6	18	8
	2 nd week	6	6	29	9
	3 th week	6	6	34	10
C (25%V 75%BC)	1 st week	6	6	16	5
	2 nd week	6	6	25	8
	3 th week	6	6	29	9

The results show that crop A had better growth and vigor results. While the lowest values were for blank crop, whose seeds did not germinate. Also affects its growth and vigor for being a degraded soil.

If we compare the results between treatments that have different amounts of vinasse and biochar, better results are obtained when the amount of biocarbon is adequate so that it does not affect the soil structure. The highest growth occurred in treatment A that had 75% of weight in vinasse and 25% of weight in biocarbon followed by treatment B (50% V 50% BC) and finally treatment C (25% V 75% BC).

4. Conclusions

- Results of the physicochemical analysis of vinasse showed that it is a liquid with high content of nutrients such as nitrogen (1279.6 mg/L), potassium (2375 mg/L), calcium (942 mg/L) as well as organic matter.
- The application of vinasse to the sandy loam soil of Tambo Grande district showed a favorable effect by improving the permeability of the soils, and decreased the sodium concentration and the excess salts to a level where they ceased to be saline - sodium (EC = 1.46 and PSI = 0.49) and with a 99% sodium removal efficiency level.
- The organic matter in soil initially was practically null, so the metabolic effect of the bacteria was fundamental to increase this percentage. In addition, there was an increase in available nutrients in the soil such as potassium and phosphorus, so much more species can be grown in the soil that are not tolerant to high amounts of salts.
- Calcium decreased with the application of vinasse and in the washes with water, so a greater contribution in reserach is necessary to avoid the lack of this nutrient in the soil.
- The effect of salt removal is reflected in an increase in the sodium concentration and electrical conductivity in leachates that gradually decreases because the soil has already depleted most of the sodium present in it.
- The soils treated with vinasse when applying biocarbon improved in their growth and vigor, specifically for which 25% of biocarbon was added in mass, concluding that this relation is the most adequate to complement the recovery of the soil.
- Obtaining biocarbon is an economical, effective and environmentally friendly alternative, since it retains carbon in the soil and decreases greenhouse gases, in addition it increases the retention of liquids and nutrients reason why less and less necessary use of chemical fertilizers is.

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