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Research article

Sustainable use of paper sludge from the Colombian paper industry

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Abstract: The paper industry is an important component in the Colombian economy, the need for the continuous use of paper and cardboard in different activities results in the generation of paper sludge, for this reason there is an imminent need to generate alternatives for the use of these industrial wastes. which have been on the rise in recent years.

This study is divided into two stages, the first is the evaluation through experimental analysis of the demonstration of the effectiveness of paper mud as an important source of carbon in composting processes, the second is the life cycle analysis (LCA) of the Alternative replacement of Composting vs. Synthetic Fertilizers.

The product obtained from the evaluation corresponds to a stabilized compost with chicken manure, which is an important source of Carbon, Nitrogen and Calcium Carbonate, resulting in an environmentally sustainable alternative compared to the use of synthetic fertilizers. In the future, an increase in the use of fertilizers is expected, due to the growth of the world population, which generates an expansion of food production and an imminent need to attend to it.

The ALC provides a better understanding of the process and its environmental impacts, the results will allow us to conclude on the most appropriate management option by showing the advantages and disadvantages associated with the use of compost. Organic fertilizers, unlike synthetic fertilizers, improve the fertility, texture and structure of the soil in the long term, promoting good drainage, aeration, water retention and root penetration, in addition to contributing to the stabilization of pH in acidic soils.

The main challenges in integrating composting from paper sludge and chicken manure is to balance the C / N ratio, making a balance of the nutrient mixture and thus improving composting times, the loss of humidity, temperature gain, microbiological control and porosity.

Keywords: paper mud; industrial waste; life cycle analysis; global warming potential (GWP); fertilizer; composting; carbon footprint

1. Introduction

The continuous and increasing use of paper and cardboard in different economic activities results in the generation of paper sludge, paper sludge is a residue from the production of paper corresponding to a mixture of cellulose fiber and calcium carbonate. For this reason, an imminent need arises to generate alternatives for the use of these industrial wastes, not only in Colombia but worldwide, and to contribute to the sustainable development of this industry.

The generation of industrial solid waste associated with the production of paper and cardboard in Colombia has been on the rise in recent years, according to the latest statistics. Colombia generates approximately 633,740 tons of paper sludge per year. Of these, 25% are sent to sanitary landfills, significantly altering the useful life [1], 7% to composting processes and the surplus is integrated into other solid waste management processes. Figure 1 shows the upward growth in the generation of industrial waste associated with paper sludge in the last 6 years [2].

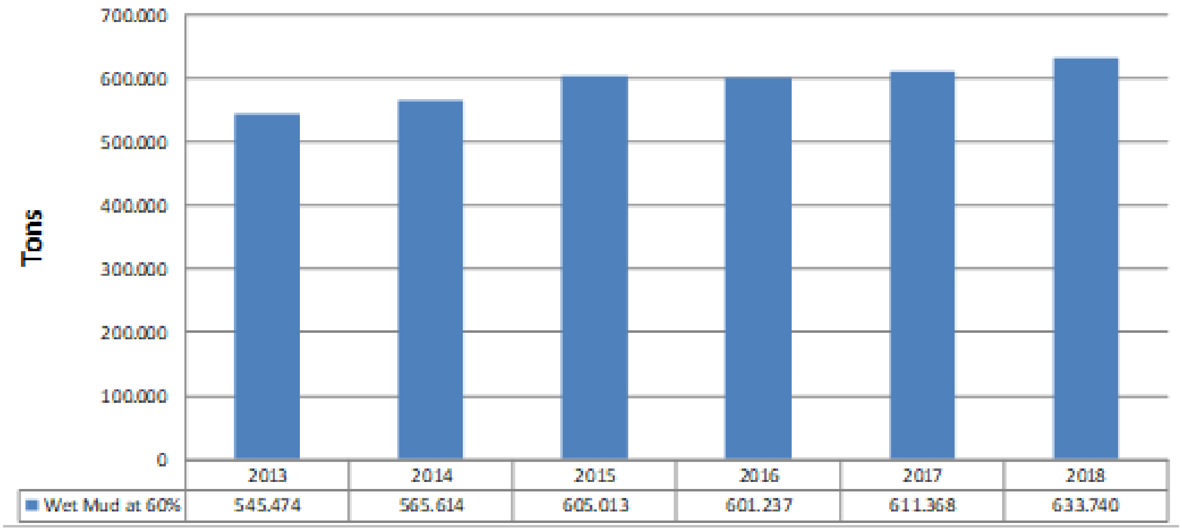

Figure 1. Tons-year of generation of paper mud in Colombia (Source: Own).

On the other hand, a significant increase in the use of fertilizers is expected in the near future. According to the projected growth of the world population, an expansion of food production will be required to meet food demand.

Irrrigated agriculture, whose area represents only 17% of all agricultural land and produces 36% of the world's food, will be an essential component of any strategy to increase the world food supply. Currently, 75% of irrigated land is in developing countries [3].

Due to its physicochemical characteristics, paper sludge is an industrial waste suitable for integration into alternative processes as a substitute raw material. The present study is carried out as a contribution to the evaluation through experimental analysis and industrial tests, to demonstrate the efficacy of the Paper sludge as an important source of carbon emission reduction, and its integration in composting processes, subsequent alternative use of agricultural fertilizers. To quantify the environmental benefits of this type of actions, the concept of life cycle analysis (LCA) will be incorporated.

In recent years, various investigations have been carried out on the use of paper sludge. In Colombia, although there is little evidence regarding the composting of paper sludge, studies on evaluations of the composting process can be found in other processes. The most relevant are presented below:

- Adriana Maria Quinchia, Marco Valencia, Jorge Mario Giraldo (2007), evaluated the use of sludge from the paper industry in preparing prefabricated panels for construction. The mixtures made of 20% plaster and 80% paper mud, showed an adequate resistance, hardness behavior as a non-structural material [4].
- Jose Luis Hoyos, Carlos A. Vargas, Reinaldo J. Velasco (2010), evaluated the result of the composting of shavings and / or sawdust mixed with chicken manure. By means of a randomized experimental design, with four treatments and two replicates, the values of temperature, pH and cation exchange were analyzed according to NTC 5167 [5].
- Garnica Daza Catalina, (2013), evaluated the classification and categorization of waste generated in the tissue and kraft paper production system, in three phases, identification of the production process, characterization of waste and identification of management, treatment alternatives , or waste disposal. The study concludes that according to multi-criteria analysis, the best alternatives for the use of paper sludge is composting and disposal in sanitary landfills [1].
- Reyes Cantor, Contreras Alfonso, (2015). Physical-mechanical characterization of the paving stone with paper sludge from the paper-making residue [6].

2. Normative analysis

Colombian regulations have an important environmental legal basis, which allows for the proper regulation and management of solid waste. In order to define the case of particular interest, the applicable regulations for the use of solid waste from industrial waste water treatment plants and their use in composting processes are mentioned below:

- Decree 2202 of 1968: Issued by the Presidency of the Republic. By which the industry and trade of fertilizers or simple chemical fertilizers, compound chemicals, natural organic, reinforced organic, amendments and soil conditioners are regulated [7].
- NTC 1927 of 2001: Fertilizers and soil conditioners. Definitions. Classification and sources of raw materials. Defines terms related to fertilizers, soil conditioners, raw material sources, and their classifications [8].
- Resolution 074 of 2002: prepared by the Ministry of Agriculture and Rural Development. By which the regulations for the primary production, processing, packaging, labeling, storage, certification, import and marketing of ecological agricultural products are established [9] .
- ICA Resolution No. 00150 of 2003. Issued by the Colombian Agricultural Institute. By which the technical regulation of fertilization and soil conditioners for Colombia is adopted [10].
- (NTC 5167 ICONTEC s. f.) NTC 5167 of 2004: Products for the agricultural industry. Organic materials used as fertilizers and soil conditioners. It establishes requirements that organic products used as fertilizers or as soil conditioners must meet and the tests to which they must be subjected. It regulates the current limitations for the use of organic materials, the physical-chemical

parameters of the analyzes of the samples of organic matter, the maximum limits of metals and lists some parameters for the microbiological analyzes (Table 1) [11].
- Decree 4741 of 2005: By which the hazardous characteristics of waste are established and other provisions are issued in this regard [12].

3. Preparation and multi-scale characterization of the paper mud

For papermaking, three main raw materials are required: Water, cellulose and recycled paper, which are subjected to disintegration, purification and formation processes. Recycled paper is used in order to reduce costs and lower the burden on forest crops, this industry is continually in search of alternative cellulose substitute raw materials, such as white writing papers, magazines, folding papers, newspapers, among others. These cellulosic fibers have the characteristic of containing significant amounts of mineral filler, added to cellulose during manufacturing to improve the structure of white paper. However, during the disaggregation processes, unsuitable residues are removed by screening equipment, as well as in water attached to fibers that are not suitable for formation, which are led to the wastewater treatment plant and Through clarification processes these solid wastes are separated and are known as paper sludge.

We are concerned about the high generation of paper sludge, the need arises to evaluate its usefulness in other production processes, in order to avoid its final disposal in sanitary landfills, the search for alternatives being the object of this study aimed at implementing the concept of the waste cycle. lifetime.

The project under investigation consists of an experimental phase which was replicated at the industrial level and consists of mixing paper mud with chicken manure, the first corresponding to a carbon source and the second to a nitrogen source. The sampling method used for this purpose was established by Colombian Technical Standard NTC 5188 Sampling Plans and Procedures for Bulk Granular Material [13].

Before determining whether or not the waste is susceptible to use, a hazard analysis was performed. Table 1 presents the quantitative results of the leaching and toxicity characteristics (TCLP) analysis of the waste [12]. They were carried out with a duly accredited laboratory between 2015 and 2018.

From the data related in Table 1, it is concluded that the sludge does not present dangerous characteristics, therefore, they are susceptible to reuse in other processes and to be used in a sustainable way.

It is important to mention that there are different use alternatives for paper sludge, among which the ceramic industry, the cement industry, biomass production and composting production stand out. This study focuses specifically on composting processes, taking the carbon present in the paper sludge from the cellulose of the plants as the main source and chicken manure as the nitrogen source.

Table 1. Maximum concentration of contaminants for TCLP test.

Parameters	UNIT	Decreto 4741 de 2005-RSLN 062 de 2007	Results Jun-15	Nov-16	Nov-17 Sludge	Compost	ago-18 sludge	Compost	Normative Complianc
Toxicity ARSENICO (TCLP) (SUB)	mg/L As	5	<0.0100	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025	complies not toxic
Toxicity BARIO (TCLP)	mg/L Ba	10	>1	14.3	>1.00	>1.00	>1.00	>1.00	complies not toxic
Toxicity CADMIO (TCLP)	mg/L Cd	1	>0.01	>0.01	>0.050	>0.050	>0.050	>0.050	complies not toxic
Toxicity CROMO (TCLP)	mg/L Cr	5	>0.20	>0.20	>0.20	>0.20	>0.20	>0.20	complies not toxic
Toxicity MERCURIO (TCLP)	mg/L Hg	0.2	>0.002	>0.001	>0.001	>0.001	>0.001	>0.001	complies not toxic
Toxicity PLATA (TCLP)	mg/L Ag	5	>0.006	>0.06	>0.01	>0.01	>0.1	>0.1	complies not toxic
Toxicity PLOMO (TCLP)	mg/L Pb	5	>0.10	>0.10	>0.10	>0.10	>0.10	>0.10	complies not toxic
Toxicity SELENIO (TCLP)	mg/L Se	1	>0.0005	>0.0005	>0.0005	>0.0005	>0.0025	>0.0025	complies not toxic
Corrosivity	Unidades de PH	<2 ; >12.5	8.36	4.04	8.36	8.98	7.56	8.38	complies not Corrosivity
Sulfide Reactivity	mg/kg			>19	>10	>10	>4	>4	complies not Reactivity
Reactivity in Cyanides	mg/kg		0.02	>0.02	>0.02	>0.02	>0.02	>0.02	complies not Reactivity
Inflammability	mm/s	>0.83	No inflamable	no inflammable	No inflamable	No inflamable	No inflamable	No inflamable	Cumple Not Inflammability

Source: Institute of Environmental Hygiene [14].

3.1. Pilot test design and execution

During the pilot test the characteristics of the material were determined. That is, its structure, porosity, water retention and other physical characteristics, in order to define the correct way to compost with the nitrogen source until obtaining a friendly product to incorporate with the soil.

The process was carried out manually, turning the piles directly in batches of 100 kg of sludge and 100 kg of nitrogen source, that is, maintaining the 1: 1 ratio. A covered area was adapted to control the humidity of the environment and to retain the temperature. During the turns, significant water losses are observed through evaporation. As the days passed, the material changed its physical appearance, going from a grayish coloration to a brown earth type.

Figure 2 compiles the results obtained with nitrogen sources corresponding to chicken manure and porquinaza, the samples were analyzed by an accredited laboratory, the recipes and proportions are their own source.

From the information resulting from the pilot test, it was concluded that the "mud / manure" ratio is efficient, both for chicken manure and porquinaza, providing the carbon and nitrogen required by the soils. Its maturation process ranges from 35 to 40 days. as long as optimum temperature control is carried out, in ranges per cell of 35 to 55 degrees, humidity between 45 and 60%, pH between 4.5 and 8.5. It should be noted that in order for the composting process to be carried out aerobically, daily or weekly turning must be guaranteed according to the behavior of the temperature of the pile, otherwise insufficient water evaporation and anaerobic precursors of bad odors will be generated.

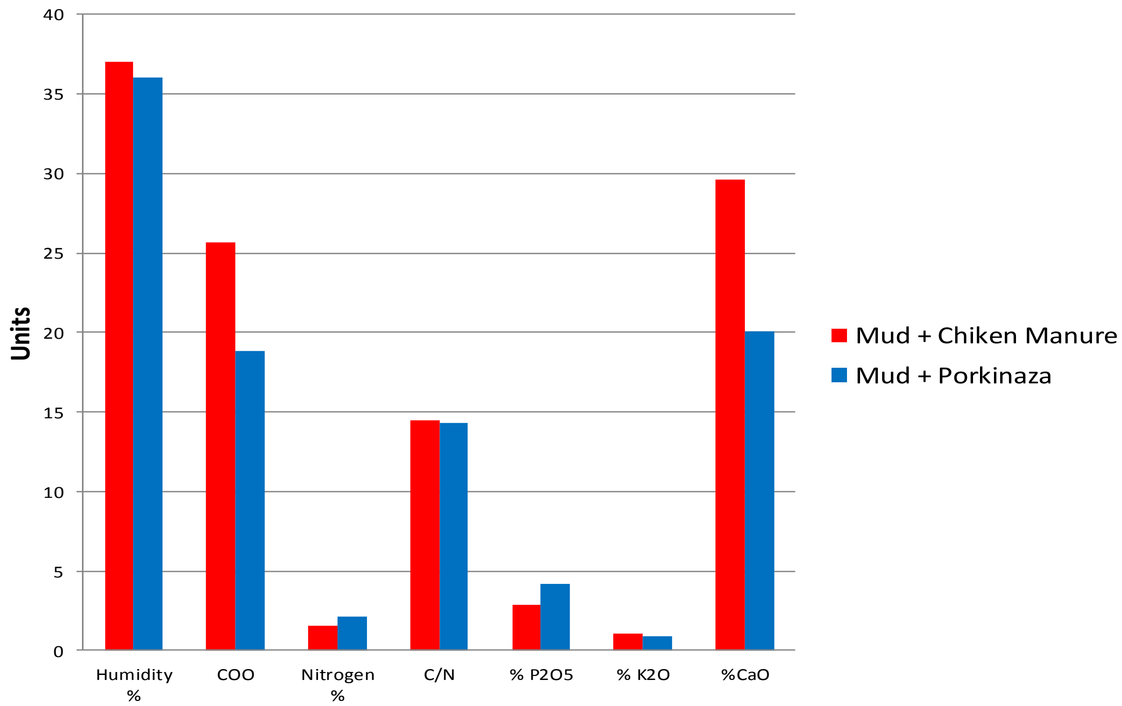

Figure 2. Comparison of physicochemical properties between mud composted with porquinaza and mud composted with chicken manure (Source: Own).

The ideal C / N ratio should be 15:1–35:1[15]. If the ratio is greater than 35, there are materials with a high amount of carbon in the mixture and therefore, the mass tends to cool and the process is slower, if it is less than 15, it indicates that there is a high amount of nitrogen in the dough, the mixture heats up and generates bad odors associated with ammonia.

3.2. Scaling the pilot test results

Taking the results of the pilot test, the design and development of a larger scale test proceeded. For the industrial test which was carried out in the Bogotá Savannah at a height of approximately 2500 meters, an average temperature of 17 ° and a relative humidity that ranges between 60 and 80%, it was preferred to use chicken manure for availability, management and generation of odor. The project consisted of the adaptation of a covered and waterproofed area of approximately 7000 square meters greenhouse type, in the area, controls of turning, humidity and temperature were established according to the farmer's manual [15]. Due to the continuous rainfall in the area, it was decided to cover the test area with a greenhouse-type cover so as not to generate increased humidity in the piles with rainwater, impacting the process by increasing the composting time, possible leaching and low temperatures.

The formation of pyramid-type piles with a base of 4 meters by a height of 1.6 meters was carried out, the process consisted of forming piles with 100 tons of material to which a contribution of 7 percent by weight was made of chicken manure. Once the pile was ready, a first turning was carried out to homogenize the material, later, according to the temperature profile, turning was carried out, the batteries undergo two processes, a first mesophilic stage, in which an increase in ambient temperature is detected until reaching at 45 ℃, then a thermophilic stage is presented, where the cell increases the temperature to approximately 55 ℃, at this temperature the cell vaporized enough water during turning, in addition, there was a significant physical change in color and grain size Going from a pasty state to a granular state, if the tumbling process was continued, the material dried until it took on the appearance of dust.

The behavior of temperature and humidity for 90 monitored cells during one year is presented in Figure 3 below.

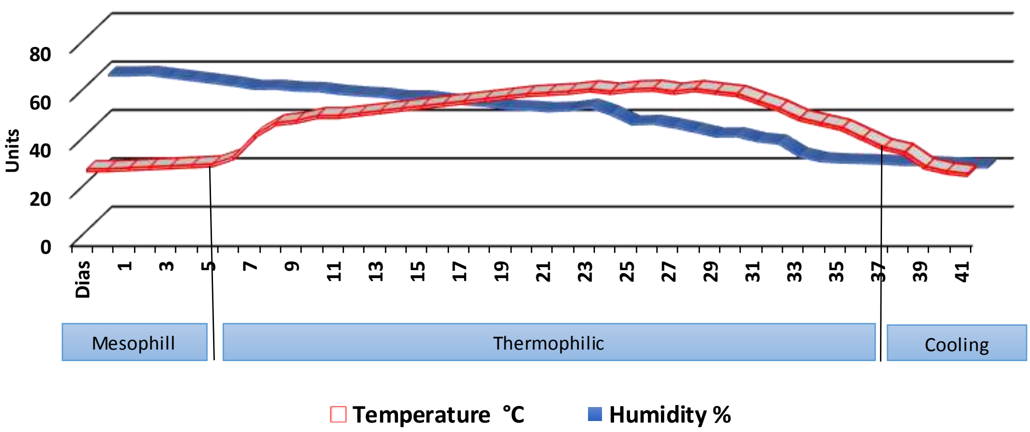

Figure 3. Behavior of Humidity and Temperature in the Composting Phases (Source: Own).

As observed as the internal temperature of the pile increases, there is a significant loss of moisture released during the flips, until the material stabilizes and reaches the expected temperature and humidity conditions, the ideal temperature should be close to ambient temperature and humidity less than 35%.

It is important to mention that the nutrients in the soil are divided into macro and micronutrients, depending on the amounts that the plant needs (See Figure 4). The primary macronutrients are nitrogen, phosphorus, and potassium, and the secondary ones are Magnesium, Sulfur, and Calcium.

Micronutrients are required in very small amounts, but are generally important for planand animal metabolism. These are iron, zinc, manganese, boron, copper, molybdenum, and chlorine [16].

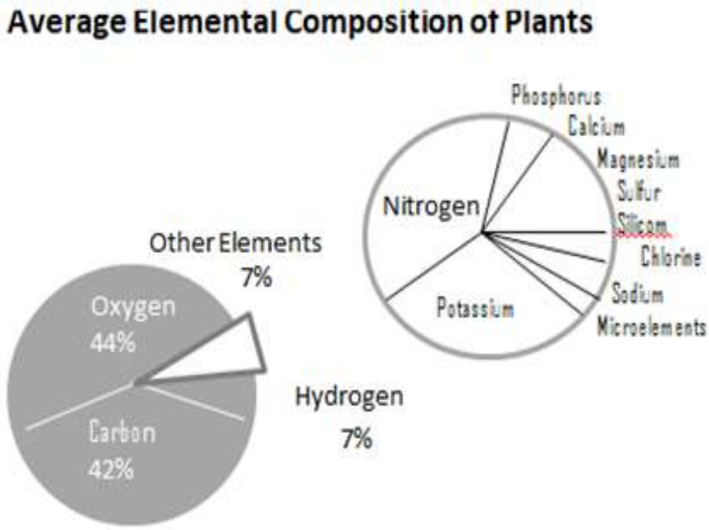

Figure 4. Average elemental composition of plants [16].

The composting times for the paper mud were determined to range from 45 to 55 days, being a direct function of the initial humidity, this time includes the cooling and stabilization time of the material, which is approximately 10 days.

Table 2 presents the results of the analyzes of the composted material and compares them with the NTC 5167 standard, which is applicable as a reference for materials to be used as a soil conditioner:

Table 2. Characterization and composition of solid organic material-compost.

Heavy metal Content in organic material	Limits Agriculture Use (LUA) ppm	Detection (L.D) ppm	Cuantification (L.C) ppm	Results ago-16 ppm	ago-17	abr-18	Analitical Method
Arsenic	41	1	3.3	N.D.	0.54	N.D	Abs. Atomic
Cadmium	39	0.01	0.04	N.D.	0.12	N.D	Abs. Atomic
Chrome	1200	0.002	0.006	N.D.	8.3	9.7	Abs. Atomic
Mercury	17	1	3	N.D.	N.D.	N.D.	Abs. Atomic
Nickel	420	0.01	0.04	9.1	36	5.62	Abs. Atomic
Lead	300	0.1	0.2	N.D.	1.8	N.D.	Abs. Atomic

Source: laboratory agrilab registry ICA according to resolution 001271 of May 5, 2014 [17].

For all the heavy metals evaluated, the results were below the limits established in the Colombian Technical Standard-NTC 5167 or were not detected by the technique. In relation to the optimal parameters of soil conditioners or fertilizers, the data in Table 3 below is presented.

Table 3. Physicochemical analysis of paper Mud.

Heavy metal Content in organic material	Units	Results dic-16 Sludge	Compost	ago-17 Sludge	Compost	ago-18 Sludge	Compost	analytical method
Humidity	%	70.9	11.4	52.5	35.12	61	18.5	Gravimetric (NTC 5167)
Oxidizable Organic Carbon (COO)	%	10.7	10.5	8.09	10.3	7.75	12.3	Walkley Black (NTC 5167)
pH		7.65	7.51	8.23	8.24	7.59	7.22	Potentiometric
Moisture retention	%	103	121	177	144	140	144	Gravimetric (NTC 5167)
C/N		68	10.5	45	18	65	18	
Nitrogen	%	0.16	1.66	0.18	0.56	0.12	0.69	Micro-Jjeldhal (NTC 5167)
phosphorus	%	0.07	0.66	0.04	0.3	0.05	0.38	Colorimetric (NTC 5167)
Cation Exchange Capacity	me/100g	9.9	23.6	21.7	39.1	18.8	52.8	Volumetric (NTC 5167)
electric conductivity	dS/m	0.8	5.55	1.46	3.69	0.88	6.35	Conductimetric

Source: Agrilab Laboratory Registration before ica according to resolution 001271 of may 5, 2014 [18].

From the data presented in Table 3, it is inferred that the material obtained has a low concentration of heavy metals, being a material suitable for incorporation into the soil as a soil conditioner. In general terms, the results of the revised analyzes are within the normal ranges for a solid organic fertilizer or fertilizer according to the Colombian Technical Standard-NTC 5167. Another outstanding benefit of this material is its high capacity for moisture retention, which it is gradually released to the ground in dry seasons; what is called a sponge effect

However, to maximize the benefits of the final product, it is necessary to balance the C / N ratio, during the process, making a balance of the nutrient mixture and thus improving composting times, loss of humidity, and temperature gain. , microbiological control and porosity. In relation to the presence of macronutrients such as phosphorus and potassium, the concentrations are low, so it is recommended to review the needs of the soil for each application and in case an additional contribution is required to meet the soil requirements. Regarding the silicon values obtained from the analyzes, they were found in a range of 4.5 to 6%, which provides resistance to the cell walls and strengthens the stems in the plants, allowing them to transport nutrients more easily.

Compost characterization is a fundamental element to know the fertilization contribution to the soil. However, an evaluation of the environmental performance of the mud allows establishing the environmental impact and comparing it as a replacement for non-composted fertilizers. For this, a life cycle analysis (LCA) was performed.

3.3 Life cycle analysis of the composting process

The cradle of the composting process begins when the organic material becomes waste. Below is a detailed diagram of the composting system. The process begins with the internal transportation of the waste paper sludge to the composting facilities and ends with the application of the compost in the soil, the benefits of applying compost to the soil are also taken into account as seen in Figure 5.

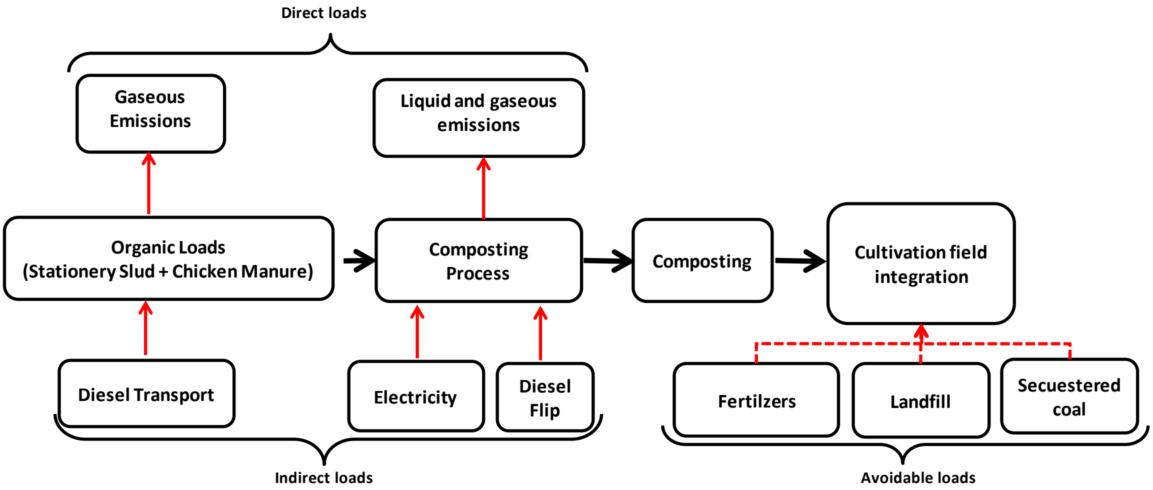

Figure 5. Flow chart of the composting process [19].

3.3.1 Transport

The composting plant under study is located at the point of generation of organic waste, so the transport distances are in the order of meters, for this reason the impact estimate is not carried out for transport reason.

3.3.2 Composting process

An important methodological assumption in waste management LCAs, this is in relation to the upstream system boundary, which is normally assumed to start at the point of waste generation. Ekvall et al., 2007 [19].

This simplification is sometimes called the zero-load assumption, which suggests that waste does not carry any of the previous loads to the waste management system Ekvall et al., 2007 [19].

The life cycle inventory consisted of direct, indirect and avoided charges:

Direct loads: They are the impacts generated by the process and are calculated with the actual data from the composting process. Indirect charges: These are the impacts associated with the use of materials and services that are used during the composting process. Indirect charges will be calculated using life cycle inventory from available databases such as producing materials and energy / fuels, such as the European Life Cycle Database (ELCD) and the Life Cycle Inventory Database of the United States (USLCI).

Avoided Charges: The avoided loads are the processes, materials and services that will not be used when carrying out the composting process. In our case, we reduce the use of artificial fertilizers, the use of sanitary landfills and increase the sequestered carbon in the soil.

The basic formula for calculating environmental performance is:
Direct charges + Indirect charges − Charges avoided = Environmental performance.

4. Comparative evaluation of compost and synthetic fertilizers based on life cycle analysis (LCA)

Life cycle analysis (LCA) is a methodology by which the environmental impacts of a process, product or service are evaluated from its "cradle" to its "grave". With this methodology it is possible to analyze and compare the process of production and use of natural fertilizers (composting) and synthetic fertilizers in order to determine some environmental impacts. The analysis was based on the methodology established in the Colombian Technical Standard NTC ISO 14040 [20].

Life cycle analysis (LCA) consists of four phases: Defining the object and scope; Inventory analysis; Impact assessment and interpretation.

In this case, the objective will be to evaluate the management of organic waste from paper mills, taken to the composting process, as an alternative to the use of synthetic fertilizers. This in order to make the comparison between the two fertilizers (composting from paper mud vs. artificial fertilizers); The production of one ton of fertilizer was taken as the functional unit.

The comparison focused on calculating the inventory of global warming greenhouse gas (GHG) emissions, or measuring the carbon footprint. To achieve this objective, the Global Warming Potential (GWP) category, equivalent to the inventory of GHG emissions potential for each sub-process, was selected; the selected method was that of emission factors. Once the emission potential was calculated, its equivalent in kg of carbon dioxide (CO_2eq) was calculated using the GHG tables. The data obtained were compared with each other to determine which provided the lowest heating potential [21].

Nutrients needed by plants are taken from the air and soil, if the presence of nutrients in the soil is large, crops will probably grow better and produce higher yields. However, if even one of the necessary nutrients is scarce, plant growth is limited and crop yields are low. Consequently, in order to obtain high yields, the use of fertilizers has been increased to provide crops with the nutrients from the soil that are lacking. With fertilizers, crop yields can often double or even triple [16].

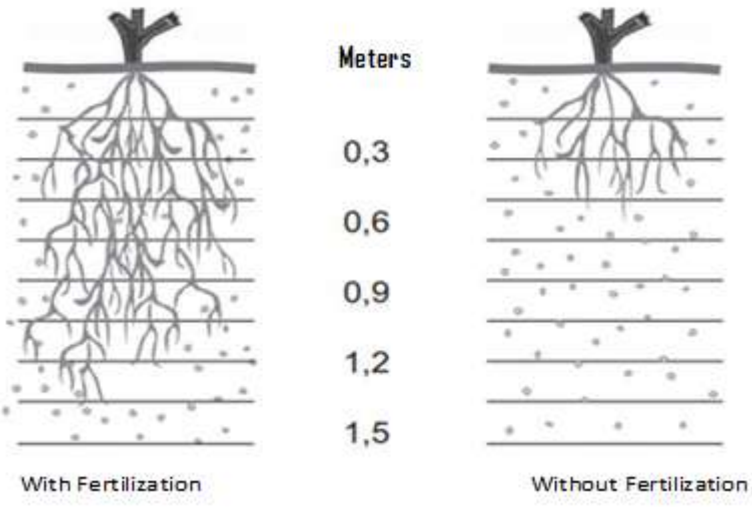

Figure 6. Depth of the roots of plants with and without fertilization [16].

Waterlogging, desertification, salinization, and erosion problems are increased by another serious environmental effect, which is the degradation of the quality of groundwater and surface water resources, by the effect of salts, agrochemicals and toxic leachates generated by dragging or overuse of fertilizers.

Agricultural pollution is a cause both directly and indirectly, causing effects on human health. According to WHO reports, nitrogen levels in groundwater have increased in many parts of the world as a result of "intensifying agricultural practices". This phenomenon is well known in some parts of Europe.

The need to maintain fertilization processes in agricultural areas to satisfy demand, added to the detriment of soil quality due to the use of fertilizers, generate important changes in soil structure, causing nitrate levels to have increased in some countries, up to the point that more than 10% of the population drinks water with nitrate levels higher than the norm of 10 mg / l. Although the WHO believes that there is no significant link between nitrate and nitrite and human cancers, the guideline on drinking water has been established with the aim of avoiding methemoglobinemia, to which infants are especially exposed [3].

It is from this analysis that the imminent need to find a solution to two existing problems arises: The first is the incorporation of the term of the life cycle of industrial waste from paper mills, that is, the search for its incorporation in processes that contribute to the improvement of the environment, and the second, the minimization of the use of synthetic fertilizers, which, even when they are useful and necessary to accelerate and improve the quality of the crops, generate important impacts on the soil, water and health.

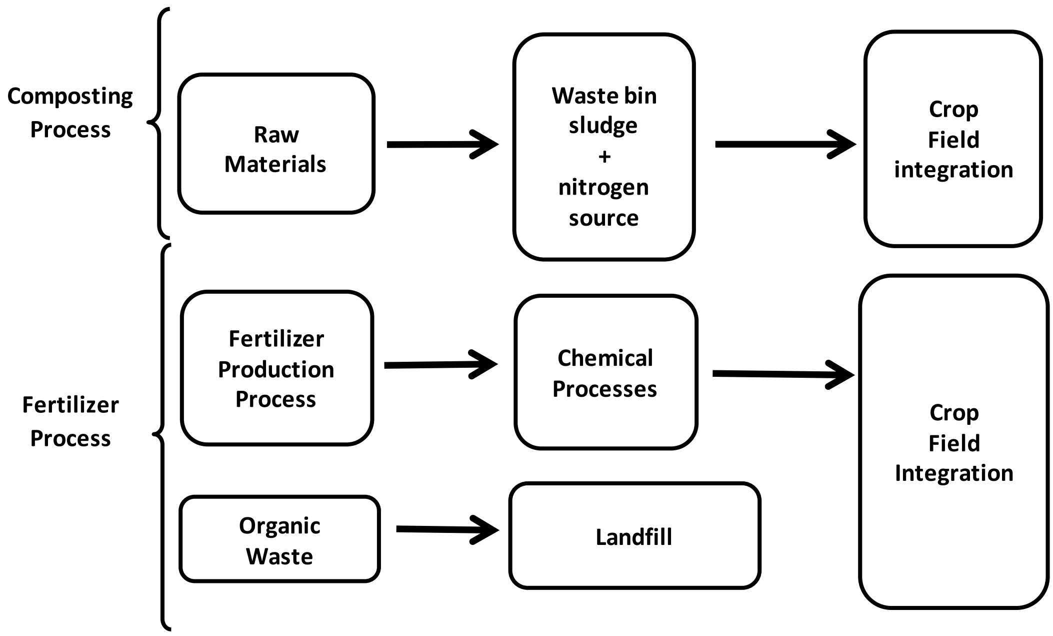

Figure 7. Composition of composting process and fertilizer production process [19].

LCA (Life Cycle Analysis) provides a better understanding of the process and its environmental impacts. The results will allow us to conclude on the most appropriate management option by showing the advantages and disadvantages associated with the use of compost instead of products such as synthetic fertilizers. The comparison will be possible by ensuring that both processes comply with the same applications and uses. In this case, the compost complies with two main ones:1. It is a process that allows the management of a waste; 2. Obtaining a product that can act as a fertilizer.

In the case of the fertilizer production process, the process only fulfills one function which is the production of fertilizers. Therefore, in order to make the comparison with the composting process of paper mill sludge in the fertilizer production process, the management of paper sludge as waste sent to landfill must be added, this only to achieve the comparison in adequate terms (see Figure 7).

4.1. Life cycle analysis-composting

4.1.1. Composting process inventory

To carry out a survey of all the inflows and outflows of the composting process, the reported values are monthly average values observed throughout a year of operation, the operations and associated sub-processes were taken into account.

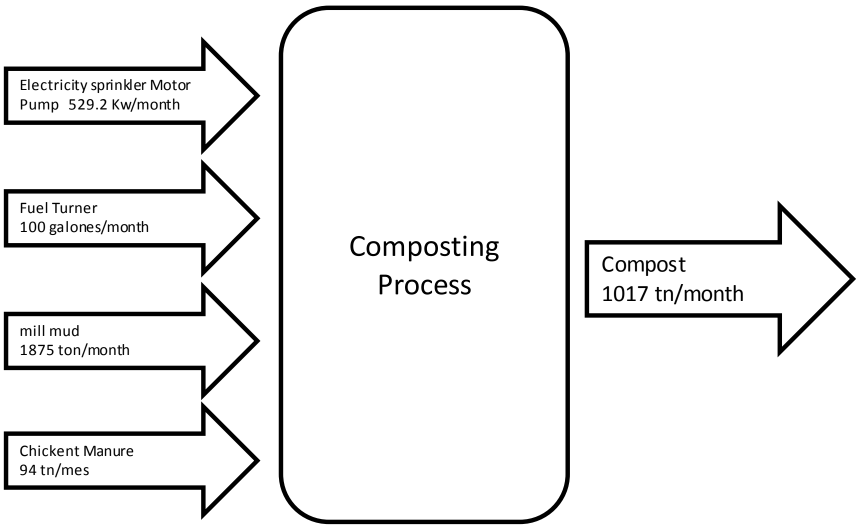

Figure 8. Inputs and outputs composting process (Source: Own). Note: The inventory of entries does not contemplate requirements or air leaks because the turning is mechanical. The process does not require the addition of water due to the high humidity of the mud and its retention capacity.

4.1.2**.** CO_2 equivalent calculation for the composting process

The values listed in Table 4 are multiplied by their respective emission factors [22]. for each case and finally a total of Kg CO_2eq for the composting process.

It must be taken into account that the total value of Kg CO_2eq corresponds to the total month, therefore, in order to generate a specific per ton of compost, this value is divided by the total tons of compost generated in the month (see table 4) [23].

Table 4. Calculation of Kg CO_2eq.

Type of Flow	Quantity(Month)	Unit	Emission Factor (Kg CO_2eq)	Kg CO_2eq
Imput				397457
Electricity			Kg CO_2eq/kwh	81
Electric motor pump aspercion	529.2	Kwh	0.153	81
Composting Process			Kg CO_2eq/gal	1039
Fuel (Turner)	100	gal	10.39	1039
Composting Process			Kg CO_2eq/tn	394805
Compost	1875	Tons	210.56	394805
Materia Prima			Kg CO_2eq/gal	1533
Mill Sludge (Dump Truck)	50	gal	10.39	520
Mill Sluge (backhoe)	60	gal	10.39	623
Chicken Manure (Dump Truck)	38	gal	10.39	390
Outputs			Kg CO_2eq/gal	3521
Compost (Dump Truck)	339	gal	10.39	3521
Leachate	0	Liters	0	0
Solid Wasted	0	Tons	0	0
Total	Kg CO_2eq total Month			400978
Total	Kg CO_2eq/tn of Composted Mud			214

4.2. Life cycle analysis-Manufacture of synthetic fertilizers

The synthetic fertilizers or fertilizers applied to the soil are made up of NPK nutrients. (Nitrogen, phosphorous and potassium); The exact components of the fertilizer are as follows: Nitrogen: Calcium and Ammonium Nitrate (CAN); Phosphorus: Superphosphate; Potassium: Potash (potassium chloride).

The production of mineral fertilizers involves the use of energy and other materials that result in a release of greenhouse gases. European average data on fertilizer production was assumed for this study, because there is a wide range of values. The global warming potential (GWP) of fertilizers is given in CO_2eq. GWP figures are presented per kg of elemental nutrient [19].

Table 5. GWP values for basic elements in fertilizer production [19].

Nutriente	Value GWP	Units	Reference
Nitrogen	8.76	Kg CO_2eq	Herman et al (2011)
Phosphorus	1.28	Kg CO_2eq	Boldrin et al (2009)
Potassium	0.7	Kg CO_2eq	Hansen et al (2006)

The variability between the different sources already mentioned is due to the combination of energy considered for the production of electricity in the manufacture of fertilizers, that is, if the energy used is produced by a thermoelectric will have a different factor than that produced by a hydroelectric and thus for each case alternative material.

4.3. Life cycle analysis-landfills

It is modeled by taking data from a typical landfill with basic and surface seal joints. The processes considered are the environmental loads resulting from the emissions of the gas from the landfill into the atmosphere and those generated by the processes carried out on the landfills. They are considered leachates in a wastewater treatment plant.

It is considered for the treatment of a tonne of waste mud in a conventional landfill that the quantity of kgCO_2eq is 434.73 [19,23].

4.4. Carbon Sequestered in the Ground

The application of compost as organic fertilizer, promotes over time an accumulation of carbon in the soil, which could be a powerful sink for sequestered carbon; various authors such as Blegini (2008), estimate that the carbon sequestration capacity in the soil may be in the order of 133–213 kg CO_2eq./ ton of mature compost integrated into the soil. Other authors such as La ROU (2003), calculate the sequestration capacity data expressed in CO_2 as 275 kg CO_2eq and 258.7 kg CO_2eq / ton of compost [19].

Under this aspect and having two possible data, it was decided to be cautious in the selection and in the use of the values to be used, for which the lowest value was taken as a reference, that is, the one supplied by Blengini (2008): 173 kg of CO_2eq / ton of compost.

4.5. Comparative process of production of compost and artificial fertilizers

Calculating the GWP global warming potentials for the composting process, fertilizer production process, carbon sequestered in the soil and for sanitary landfills, we can consolidate the results in Table 6.

Table 6. Data consolidation table.

Process	Global Warming potential (GWP)	Units
Composting	214	Kg CO_2eq/tn de compost
Artificial Fertilizers		
Nitrogen	8.76	Kg CO_2eq/kg de nutrient
Phosphorus	1.28	Kg CO_2eq/kg de nutrient
Potassium	0.7	Kg CO_2eq/kg de nutrient
Landfil	434.7	Kg CO_2eq/tn of mud
Sequestered Carbon	173	Kg CO_2eq/tn de compost

Now, for the purposes of the calculation, it was determined that the use per hectare of composting, according to the experience of application obtained in average farms is 12 tons, this value should be adjusted for each particular case according to the requirements of soil nutrients that fertilization is required.

Below in Table 7, the results of the corresponding calculations to determine the kg CO_2eq are presented. (carbon footprint) for the compost vs. fertilizer production process, these data will allow evaluating the environmental impacts generated by each process.

From the data obtained in the previous table, it can be concluded that when comparing the carbon footprint for each case, composting production reduces the volume of GHG emissions by 10,405 kg of CO_2eq per hectare.

Table 7. Calculation of the total carbon footprint for composting and for the process of artificial fertilizers.

Life circle	Quantity	Unit (un/ha)	Emission factor Kg CO_2eq	Kg CO_2eq
Composting process				
Compost	12	tn	213.9	2567
Sequestered carbon	12	tn	−173	−2076
Composting process total				491
Artificial fertilizer process				
Nitrogen	136	Kg	8.76	1191
Phosphorus	30	Kg	1.28	38
Potassium	145	Kg	0.7	102
Landfill	22	tn	434.7	9564
Composting process total				10895

5. Conclusions

Taking into account that the study was carried out in two stages, the first corresponding to the industrial test to determine the effectiveness of the mud in the production of compost, and the second stage corresponding to the life cycle analysis, the following is concluded.

Paper mud is a usable waste suitable for use as a substrate in the production of compost, the efficiency of the process and the quality of the final product depends on monitoring and controlling the variables of humidity, temperature, oxygen and pH

The behavior of the temperature and humidity of most of the piles show that the cooling and maturation or stabilization stage did not occur, therefore the final product obtained in a period of 35 to 45 days is classified as a soil conditioner If more drying is desired, the C: N ratio should be adjusted and the material should be mineralized until obtaining a powder-like product.

As for the quality values, the material complies with those established by the Colombian Technical Standard NTC 5167 for Products of the Agricultural Industry, however, it is recommended to make adjustments in the recipes to improve the C / N ratio and enhance the needs for each particular floor.

The compost obtained can be incorporated into different crops such as corn, potatoes, onions, home gardens and especially the use in pasture forage for livestock. According to field tests, the application of compost from paper sludge is beneficial in restoring degraded soils, improving the structure, porosity and moisture retention to maintain hydration during dry seasons.

The life cycle analysis is expressed as the global warming potential, which corresponds to a measurement of kg CO_2eq, the life cycle analysis method implies that the processes must be analyzed from the "cradle to the grave" For the development of this study, the inputs to the composting process were evaluated as raw materials, transportation and energy, and the outputs were the transportation of the composting process.

The footprint calculation showed for composting an emission of 491 kg CO_2eq, this value is obtained from the generation minus the carbon sequestered by the soil, however, even when this retention phenomenon will not occur in the soil, the emission of the process Composting would be 2567 kg CO_2eq. Now, for the calculation of the footprint of synthetic fertilizers, the calculated emission is 10895 kg CO_2eq, therefore from the results obtained it is concluded that the use of compost as a source of carbon and nitrogen reduces emissions by 10,405 kg CO_2eq per every hectare of fertilized soil [22].

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Conflict of interest

The authors declare no conflict of interest.

References

1. Garnica Daza C (2013) Paper sludge management alternatives in the tissue and kraft paper industry.
2. ANDI (2017) Sustainability Report 2017. ANDI.
3. Ongley E (1997) Fight Against Agricultural Pollution of Water Resources (FAO Study Irrigation and Drainage-55). Sustainable development department 4.
4. Quinchía AM, Valencia M, Giraldo JMJRE (2007) Use of sludge from the paper industry in the preparation of precast panels for construction. *Revista Ela* 2007: 9–19.
5. Concha JLH, Vargas CA, Velasco RJ (2010) Evaluation of compost obtained in a mobile pile using mixtures of cage manure with cellulosic material. Biotecnología en el Sector Agropecuario y Agroindustrial: BSAA 8: 54–60.
6. Cantor DR, Alfonso CC (2015) Physical-mechanical characterization of the paving stone with paper mud residues from paper manufacture. *Encuentro Internacional de Educación en Ingeniería ACOFI* 2015.
7. Livestock MdAy (1968) By which the industry and trade of fertilizers or simple chemical fertilizers, compound chemicals, natural organic, reinforced organic, amendments and soil conditioners are regulated, and provisions are repealed.
8. INCOTEC (2012) Fertilizers and soil conditioners. definitions, classification and sources of raw materials. NTC1927. Third ed.
9. Colombia MdAd (2002) By which the regulations for the primary production, processing, packaging, labeling, storage, certification, import and marketing of ecological agricultural products are established.
10. Agropecuario I-IC (2003) By which the Technical Regulation of Fertilizers and Soil Conditioners for Colombia is adopted: Colombian Agricultural Institute.
11. INCOTEC (2011) Products for the agricultural industry. organic products used as fertilizers or fertilizers and soil amendments or conditioners. second ed.

12. Ministry of the Environment vydt (2005) By which the prevention and management of the hazardous residues or wastes generated in the framework of comprehensive management is partially regulated.
13. INCOTEC Plans and sampling procedures for the inspection of bulk material. In: INCOTEC, editor.
14. Institute of enviromental higiene s.a.ss.a.s Ioeh (2015) Hazardous characterization sludge effluent plant paper industry. 60.
15. Román P, Martínez MM, Pantoja A (2013) Farmer composting manual: Experiences in Latin America.
16. Fao (2002) Fertilizers and Their USE a Pocket Guide for Extension Officers: Food & Agriculture Org.
17. AGRILAB (2015) Laboratory for chemical analysis of agricultural imputs.
18. AGRILAB (2015) Solid organic material composition.
19. White E (2012) A life cycle assessment of a standard Irish composting process and agricultural use of compost. rx3.
20. ICONTEC (2015) Environmental management systems requirements with guidance for use. In: ICONTEC, editor.
21. Quintana GMR (2015) EAB-ESP report on greenhouse gases (GHG) 47.
22. Ministry of Agriculture AyMA-E (2013) Composting: recipe to reduce the carbon footprint in Spain.
23. Colombia P Emission Factors-Electricity. In: Colombia CdAd.