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Compost production through the aerated static pile method

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ABSTRACT

Objective: To evaluate and validate the method of compost production by aerated static piles (ASP), in comparison with a traditional method to optimize the composting process.
Design/methodology/approach: The static pile system (ASP) was designed and established for compost production at the Huimanguillo Experimental Field (Tabasco, Mexico), where composts of different manures were used in a completely randomized experimental design to evaluate nutritional and quality parameters of the composts to compare with the traditional method.
Results: It was found that the ASP method allows obtaining composts with higher nutritive values than those generated by the traditional method. In addition, it satisfies the required quality.
Limitations of the study/implications: It is suggested to study more doses of the composts generated by ASP in different crops and stages.
Findings/conclusions: The ASP method by injecting more air during the composting process, raises microbial activity, which in turn, raises compost temperatures, achieving higher fixation of nutrient compounds.

Keywords: manures, compost, quality, aeration, organic agriculture.

INTRODUCTION

The More than 24 million hectares are organically cultivated in the world, the countries with the largest cultivated area are Australia, with 10 million hectares, followed by Argentina and Italy (Zink, 2022). Mexico occupies the 18th place in the world, with 216,000 hectares, located as a producer-exporter of organic food and the first producer of organic coffee (Forbes, 2018; Willer *et al.*, 2023).

In organic agriculture, organic matter (OM) is the fundamental basis, and many countries practice the agricultural use of residues (Ballesteros *et al.*, 2018). This agriculture contemplates the structural diversity and ecological management of the soil, which are not carried out in traditional agriculture (Oviedo-Ocaña *et al.*, 2017). Its short-term effect is

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slow, due to the nutrient content of the inputs used, remaining available to the plant for a longer period of time.

Composting is an aerobic biochemical process, which degrades organic material, such as organic residues (OR), macro and microorganisms, resulting in compost. This is a replica of the natural system of decomposition of materials, but with anthropic intervention, shortening the decomposition time of materials, improving the final product (Labrador, 2001), obtaining direct and indirect benefits to the soil, increasing the OM, nutrient content, structure and edaphic mesofauna. In composting, a complex array of microbial populations develops as a function of temperature, nutrient availability, oxygen concentration, moisture content and pH (Ballesteros *et al.*, 2018). It is necessary to maintain adequate aeration for the process to take place under aerobic conditions, as well as a humidity of 50%, thus allowing the presence of decomposing microbes. Composting is a highly dynamic process, regulated by the interaction of multiple variables such as temperature, oxygen level, moisture content and accessibility to essential nutrients, all of which directly affect the microbial communities responsible for the biological decomposition process.

The active composting process goes through different phases to obtain the final product: mesophilic phase I (heating), in which the crushing of the materials by the mesofauna and the participation of mesophilic bacteria are intensified; in the thermophilic phase (sanitization), biochemical degradation by fungi and actinomycetes is intensified; and in mesophilic phase II (cooling), bacterial degradation of residual substances is pronounced and the activity of the mesofauna returns in the larger particles. Thus, composting contributes to the reduction of both weight and volume of the original materials by loss of gases and the synthesis of various substances such as water vapor, ammonia, nitrogen oxides or nitrates (according to oxide-reduction potential), sulfur dioxide, prehumified substances, assimilable elements, which results in a finished compost (García-Silva *et al.*, 2023). This method is essentially an aerobic activity; therefore, insufficient oxygen supply necessary for aerobic degradation by microorganisms leads to a significant slowdown in the decomposition of organic materials (Michel *et al.*, 2022).

Oxygenation, as a determinant of the environment, is crucial, as microorganisms require oxygen for metabolic energy generation, efficient growth and intensification of matter consumption. This oxygenation process consists of replacing the low-oxygen air present in the compost piles with a stream of fresh, oxygenated air. Under natural conditions, such gaseous exchange occurs when air heated by composting reactions rises through the pile, generating a suction effect that draws in fresh air from the surrounding environment. However, this process can be conditioned by several factors, such as wind intensity, the water content of the material and the degree of porosity present in the pile (Lim *et al.*, 2017). In this sense, the need arises to test and generate new methods to optimize the composting process in order to reduce processing times and increase the production of composts such as the composting in aerated static piles (ASP), consists of composting in elongated piles on a network of aeration pipes where air is supplied to provide an aerobic medium for composting (Longoria *et al.*, 2014).

The advantage of this method is that it does not require a periodic turning, in the initial phase an adequate mixture of materials should be given since, once the piles are built, the same control system indicates the obtaining of a mature compost (DOF, 2002). In organic agriculture under tropical conditions in Tabasco, Mexico; the optimization of the composting process is still incipient, since manual turning is traditionally done as an alternative to oxygenate the compost piles, delaying the composting process, increasing the labor requirements and therefore the production costs of the composts. For this reason, the objective of the present research is to evaluate and validate the method of compost production by aerated static piles (ASP) in comparison with a traditional method and its application in indicator plants. Furthermore, it is the first time that this type of technology has been developed to improve the production and quality of compost.

MATERIALS AND METHODS

Study sites. The work was carried out from September to November 2022 in the organic module of the facilities of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) Campo Experimental Huimanguillo, located at the geographic coordinates 17° 51' 07" N, 93° 23' 46" W. The climate of the area is warm and humid with abundant rainfall in summer, with an approximate annual range of 2,200 to 2,600 mm and absolute maximum and minimum temperatures of 14 °C and 45 °C (Salgado *et al.*, 2017). The organic module has a surface area of 300 m^2 in the open air.

Aerated Static Piles System (ASP). The structure of the system allows the establishment of three piles, it is composed of polyvinyl chloride pipe (PVC) sanitary or hydraulic type of 4" diameter, for each pile, consists of a central tube where the materials to be composted will be placed, in the final part a lid of the same material was installed to avoid air loss. The area of the pipe or main tube where the compost is placed, consists of rows of perforations in the upper middle part, each 1/2" in diameter, separated at a distance of 5 cm in length and 2 cm in width. These perforated tubes are connected to a 4" diameter ball valve of the same material (PVC), which allows the distribution of air as required, or can allow disabling the use of any tube if it is not necessary, which allows adapting the system to a certain production of compost, in smaller or larger quantities.

The keys are connected to a distributor pipe with T couplings and 90° elbows with the same dimensions and materials (PVC) which in turn is connected to the distributor pipe, which is connected with 45° elbows to the two outer piles. It also has a secondary pipe that allows directing the air to other compost piles if required, this also has a ball valve that regulates the air flow, which increases the possibility of staggered production.

The directional tubes are connected to a centrifugal extractor with a WEG® brand electric motor with a capacity of 1/3 HP, configured for nominal work of 127/220 volts, which couples a Francis type turbine, with a spiral or snail box of 26-gauge smooth sheet, with a distributor or impeller with galvanized sheet blades of 10 cm wide with a suction mouth of 8" and exhaust outlet adapted to a 4" pipe, providing a constant air supply of 7,600 m^3/hour (Figure 1).

For the joints of the materials, it is recommended to use PVC glue, in order to avoid air loss in the joints of the pipes and faucets, and to maintain a correct flow towards the compost piles. Aeration of the pile is done twice a day, the interval is determined by the external

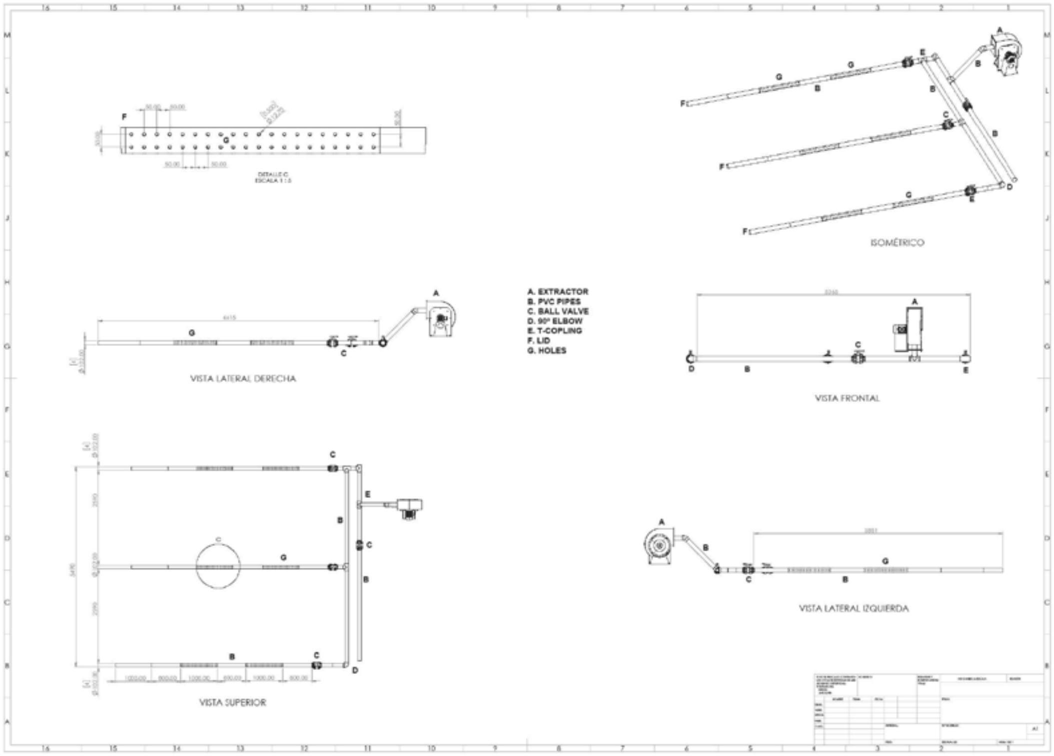

Figure 1. Design of the Static Pile System for compost production at the INIFAP-Huimanguillo Experimental Field.

temperatures, emphasizing that these are done during the hours of higher temperature, which can be from 30 minutes to 2 hours as required. The system can continuously supply air to the composite stack. This will be determined by size, type of materials, job site and environment.

Method validation. The validation method of the ASP system was compared with the traditional methods of compost production, which in the same way was established in the organic module of the INIFAP-Huimanguillo Experimental Field. Twelve beds measuring 1.40 m long and 1.40 m wide were used, with a 15 cm thick sand base, thus avoiding direct contact with the soil, and a plastic bag was placed on top of this base to avoid leaching of the composts (Figure 2).

Three types of manure were evaluated for a period of 72 days: bovine (treatment 1), horse (treatment 2) and sheep (treatment 3) in a completely randomized experimental design with three replicates each, and a control for each treatment, placed in the same way in the tubes of the aerated method. The useful bed was 1.20 m long by 0.80 m wide, with a space of 0.50 m between each bed. The treatments used in both methods had the same composition, modifying only the type of manure used. The formulation used was manure (bovine, sheep or horse) 50% of the wet weight, 20% of loam (forest soil), 10% of fresh weeds, 5% of ash, 5% of phosphoric rock, 5% of sawdust, 5% of cocoa husk, 1% of molasses. The methodology used for the composts consists of sieving, grinding, weighing, mixing and humidity of the mixtures.

Figure 2. Organic Module and evaluation beds in the INIFAP-Huimanguillo Experimental Field.

The variables taken during the evaluation period were: temperature inside the compost, temperature, environment and humidity, which were taken with a Brannan® brand alcohol thermometer with a capacity of up to 150 °C, introducing 15 cm inside the compost to obtain the humidity of the different piles. For relative humidity, a Sharp® Model 63-1032 digital thermohygrometer was used; the sensors were introduced in the center of the different piles to obtain this data. In addition, a physical-chemical analysis was performed to determine the nutritional contribution of the different composts (treatments) according to the Official Mexican Standard NOM-021- RECNAT-2000 and the Official Mexican Standard NMX-FF-109-SCFI-2008 (DOF, 2008), taking random samples for each treatment.

Evaluation of composts with habanero chile (*Capsicum chinense* Jacq.) as indicator plant

The composts obtained from the different treatments were evaluated by means of indicator plants, using habanero bell pepper (*Capsicum chinense* Jacq.) plants obtained from a commercial nursery with 45 days of germination. A completely randomized design with six treatments and four replications was used for the evaluation. The treatments consisted of compost percentages equivalent to 25%, 50%, 75% and 100%, plus an absolute control (100% sand) and a chemical treatment with application of fertilizer with an application formula of 180-180-150 (N, P, K). Sand was used as a complementary inert substrate, so that there was no external incorporation of other nutrients and the effect of the composts was reflected.

Two habanero bell pepper seedlings were used per 30×15 cm black polyethylene bag filled according to the treatments mentioned above, obtaining a total of 56 bags and 112 plants. The plants were established in the greenhouse of the Huimanguillo experimental field, in order to reduce the effect of pests and diseases. The agricultural practices used were daily irrigation with 500 ml of water per bag, control of fungi and mites with fungicide (Propamocarb+Fosetyl and Carbendazim).

Weekly data were collected for a period of five weeks to obtain the development of these plants. The variable evaluated was plant height. This data was obtained with a graduated ruler, starting from the base of the apical plant of the head. An analysis of variance and mean test (Tukey p=0.05) was performed with the SAS statistical package (SAS, 2004).

The composting process, both traditional and ASP, lasted 37 days, in which the ASP system was supplying air to the composts. The effect of the method was reflected in the variables evaluated during the active period, which allowed the elaboration of composts by both methods, with the variables described below.

RESULTS AND DISCUSSION

Behavior of environmental variables. Temperature, composts finalized using the aerated static pile system showed a maximum temperature of 49 °C and a minimum of 28 °C, with an overall average of 26.1 °C. During the thermophilic phase, internal compost temperatures can increase by up to 45% (Docampo, 2013). The highest temperature peaks occurred on days 13, 19, 22 and 30, representing 48% of the evaluation period.

Aeration reduced temperature peaks, contributing to the sterilization of pathogens, molasses seeds and other harmful microorganisms. For non-aerated composts, the maximum temperature was 48 °C and the minimum was 27 °C, with a mean of 32 °C, the maximum temperatures were reached in the period of 19 days, similar to the behavior of a traditional compost (García-Silva *et al.*, 2021).

Microbial activity increases the temperature, an exothermic process essential for rapid decomposition of organic matter, which must be maintained between 30 °C and 60 °C, since below this temperature the decomposition process slows down and above this temperature microorganism cannot survive (Ruíz, 2013).

Humidity, was monitored manually and maintained in an optimum range of 70-80% by applying water with molasses. Relative humidity presented a maximum of 90% before aeration and a minimum of 41%, with an overall average of 77.8%. During aeration, the maximum humidity was 83% and the minimum 41.3% with an overall average of 68.2%. Although the humidity decreased, it remained within the optimum range of 40-70%, suitable for the composting process (García-Silva *et al.*, 2021). Relative humidity is crucial for the availability of water in the compost, essential for microbial activity (Zhang *et al.*, 2021). This is relevant in the environmental conditions of the state of Tabasco, which is considered a with excellent humid tropical conditions, where relative humidity exceeds the national average due to its humid climate (Olvera-Rincón *et al.*, 2024).

Physico-chemical analysis. During decomposition, the pH of the composts increased, ranging from 7.5 to 8.5. The compost aerated with sheep manure presented the highest pH (8.04). These values are different from those found in previous studies in Figueroa (2014) and Ge *et al.* (2022), which reported a pH of 7.5 and 6.82, respectively. Higher pH in aerated composts indicates better substrate decomposition. The composts contain less exchangeable hydrogen ions, more calcium and magnesium (Meena *et al.*, 2021). Analyses showed higher amounts of these minerals in aerated composts compared to the traditional method Table 1.

Table 1. Physico-chemical analysis of bovine, sheep and horse manure composts with ASP aeration and traditional method without aeration.

Identification	**pH**	**EC**	**OM**	**N**	**P**	**K**	**Ca**	**Mg**	**Na**	**CEC**	**Fe**	**Cu**	**Zn**	**Mn**	**Humidity**	**Ashes**	**OC**	**C/N Rat.**	**AD**
Description		**dS m^{-1}**	**%**		**mg kg^{-1}**	**cmol (+) kg^{-1}**					**mg kg^{-1}**				**%**				**G mL^{-1}**
Bovine manure without aeration	7.52	2.33	60	2.10	35.64	2.00	5.56	1.43	0.30	43.82	95.61	43.77	10.05	10.9	24.54	22.10	34.80	16.57	0.52
Bovine manure with aeration	7.31	2.51	65	2.35	39.75	2.51	6.30	1.82	0.35	48.63	108.90	54.81	10.80	11.4	26.76	24.70	37.70	16.04	0.54
Horse manure without aeration	7.95	2.03	59	2.48	43.55	2.62	6.86	2.15	0.55	53.28	201.04	66.75	14.93	10.1	25.10	20.03	34.22	13.80	0.65
Horse manure with aeration	8.15	2.08	62	2.71	49.26	2.90	7.87	2.62	0.59	56.86	215.78	81.34	15.68	11.6	27.20	20.20	35.96	13.27	0.68
Sheep stool without aeration	8.05	2.12	63	2.52	51.82	2.45	7.82	2.61	0.68	58.37	248.20	78.10	17.41	14.1	33.58	24.78	36.54	14.50	0.72
Sheep stool with aeration	8.61	2.45	68	2.95	56.01	2.73	8.80	2.97	0.80	60.15	268.89	83.44	18.62	15.3	34.45	25.16	39.44	13.37	0.75

Electrical conductivity (EC), according to the Mexican standard NMX-FF109-SCFI-2008 (DOF, 2008), EC values in the composts were maintained within the optimal range (<4 dS m^{-1}), coinciding with the results reported in Vázquez *et al.* (2017). Higher values can reduce plant growth and cause soil salinization (Orden *et al.*, 2021).

The analyses showed that the amount of organic matter (OM) in the aerated and non-aerated treatments had an overall mean of 60%, exceeding the content established by NMX-FF109-SCFI-2008, which differs with the OM values (50.06% and 54.06%) in a study under similar conditions in Whang *et al.* (2022).

Macronutrients: nitrogen, phosphorus and potassium, in the composts were superior compared to the traditional method, all within the ranges established by NOM-021-RECNAT-2000. The nitrogen content was higher than those reported in Qiu *et al.* (2021).

Although nitrogen is lost in the thermophilic phase (García-Silva *et al.*, 2021), aeration reduces this loss. Phosphorus levels were lower than those reported in Liu *et al.* (2023), but not toxic. The composts under this method maintained high potassium levels.

The Caption Exchange Capacity (CEC) contained in aerated composts was found to be: Sheep 60.15 cmol ($^+$) kg^{-1}, Horse 56.86 cmol ($^+$) kg^{-1}, and Bovine 48.63 cmol ($^+$) kg^{-1}, higher than those found in the traditional method: Sheep 58.37 cmol ($^+$) kg^{-1}, Horse 53.28 cmol ($^+$) kg^{-1}, and Bovine 43.82 cmol ($^+$) kg^{-1}, the results obtained were similar in Vázquez *et al.* (2017).

Microelements: Iron (Fe), Copper (Cu), Zinc (Zn), Manganese (Mn). The composts with the ASP system showed higher amounts of these elements compared to the traditional method, all within the ranges established by NOM-021-RECNAT-2000.

Carbon to nitrogen ratio (C/N). The ratio obtained in this element in the different substrates with the ASP system was: Bovine 16.04, Sheep 13.37, Horse 13.27, similarly a minimal but greater difference was obtained in the treatments with the traditional method, which were: Bovine 16.57, Sheep 14.50, horse 13.80, unlike the sheep treatment which was presented higher in the traditional method to the aerated ASP treatment. According to NMX-FF-109-SCFI-2008 (DOF, 2008), the data obtained are within the indicated range. A C/N ratio between 12 and 20 is necessary for stability and maturity (Li *et al.*, 2022).

The Bulk Density (AD) obtained was within the indicated range (0.40 to 0.90 g/ml^{-1}), according to NMX-FF-109-SCFI-2008 (DOF, 2008), and higher than reported in Peña *et al.* (2020).

Aeration favors the activity of aerobic microorganisms, such as bacteria and fungi, which efficiently decompose organic matter. These microorganisms require oxygen to carry out their metabolism and oxidize complex organic compounds, such as carbohydrates, proteins and lipids, into simpler compounds (Nguyen *et al.*, 2020). This oxidation process produces carbon dioxide. (CO_2), water (H_2O), and heat as subproducts. In aerobic composting, decomposition occurs primarily in the presence of oxygen, resulting in faster and more controlled decomposition than in anoxic conditions, where decomposition can be slower and less efficient, producing compounds such as methane (CH_4), which is a greenhouse gas (Peng *et al.*, 2023).

The oxidation of organic compounds was favored by ASP since the method presented the highest nutrient values of N, P, K, Ca, Mg, Fe, Cu, Zn and Mn, which makes the ASP composted manure product valuable for its nutrient contributions (Elmrini *et al.*, 2022). CO_2 generated in the aerobic process is easily manageable and does not contribute significantly to climate change, unlike methane. In addition, aerobic decomposition also generates compounds such as volatile organic acids (acetic acid, formic acid) and essential nutrients (nitrogen, phosphorus and potassium), which enhance the compost and make it more beneficial to the soil (Michel *et al.*, 2022). Our findings are similar to those reported in other works where the composting process was optimized through ASP compared to traditional aeration methods, where nutritional values were higher in composts processed by ASP method (Table 1), than traditionally (Íñiguez-Covarrubias *et al.*, 2019; Abdoli *et al.*, 2019; Bondeson *et al.*, 2023). The control of aerobic conditions also prevents the formation of toxic compounds such as hydrogen sulfide. (H_2S), which is produced under anaerobic conditions and can be detrimental to both microorganisms and plants (Manga *et al.*, 2023).

Compost pH is a crucial factor affecting microbial activity and the quality of the final compost. During composting, aerobic microorganisms produce organic acids such as acetic acid, butyric acid and lactic acid, which can reduce the pH of the composted material (Bondeson *et al.*, 2023). However, aeration helps to regulate this acidification process by promoting the activity of oxygen utilizing microorganisms involved in the production of acidic com-pounds. At the same time, these aerobic microorganisms, as they break down organic matter, also generate basic compounds that act as buffers, preventing excessive pH drop. If the pH of the compost drops too low, it can become toxic to plants and negatively affect plant growth when the compost is used as an amendment. This was shown in the ASP treatments with the horse and lamb composts that ended up with a higher pH in contrast to the traditional aeration method (Table 1). Too low a pH can hinder the availability of nutrients and affect the balance of beneficial microorganisms in the soil (De los Santos *et al.*, 2022). Likewise, the microbial communities in the ASP system received more O_2, which theoretically increased microbial activity and compost temperature and more frequently, causing the specific heat to be high in water, which implies that drier compost mixtures can heat up and cool down faster than wetter ones.

Indicator plants. During the five weeks of evaluation of the indicator plants of habanero pepper, which were in the vegetable greenhouse at the Huimanguillo Experimental Field, the results of the behavior of the evaluated variable were obtained, according to each of the composts used Table 2.

In general, the chemical treatment obtained superior results in comparison with the treatments of the different types of compost (manure). The 25% and 50% treat-ments showed a similar response in the variable evaluated for the bovine compost treatment, which is similar to what was found in 2020 (Mendoza *et al.*, 2020), where similar percentages (25%-75% organic fertilization) were used in the plant height variables. In the case of sheep compost, there was no significant difference (p=0.05) between the different percentages used, but there was in comparison with the chemical treatment (Table 2). For the behavior

Table 2. Results of the height variable at five weeks of habanero bell pepper indicator plant under different concentrations of three types of compost.

Bovine compost	Mean	Sheep Compost	Mean	Horse Compost	Mean
CT	15.25* a	CT	15.25* a	CT	15.25* a
25%	11.50 ab	25%	9.25 b	25%	9.75 b
50%	11.25 ab	100%	9.00 b	50%	8.75 bc
75%	8.75 b	75%	9.00 b	T000	8.50 bc
100%	8.50 b	T000	8.50 b	75%	8.25 bc
T000	8.50 b	50%	8.25 b	100%	7.75 c
CV	20.24	CV		CV	7.96

*Means with the same letter are statistically equal (Tukey p=0.05). CT: Chemical treatment. CV: Coefficient of variation.

of the horse manure-based compost, a significant difference ($p=0.05$) was found between the chemical treatment and the 25% treatment; however, for the other percentages (50%, 75%) and the control (T000), there was no difference between the treatments, but there was a difference in comparison with the 100% percentage.

The tendency of greater vegetative growth was expressed in the chemical treatment, which may be due to the fact that, during the first phenological stages of the crop, it requires high amounts of macronutrients, including N, which could be supplied by chemical fertilization, where the availability of N is immediate (Chen *et al.*, 2021). In the case of the 100% manure treatments, the behavior of the indicator plants was similar to that of the control (Mendoza *et al.*, 2020), the behavior of the indicator plants was similar to the absolute control (T000), this may be due to the fact that manures are an important source of N in the form of ammonium $\left(NH_4^+\right)$ and nitrate $\left(NO_3^-\right)$ (Meena *et al.*, 2021), in addition to other nutrients available to the plant, which can cause a degree of intoxication by saturation in the substrate, which is expressed in the plant as slow growth, and can even cause plant death (Table 2). In addition, the composts generated by the ASP method are more nutritionally complete substrates, having more elements and in greater quantities, which is reflected in the electrical conductivity greater than 2 dS m^{-1} of the evaluated materials (Michel *et al.*, 2022). In addition, habanero bell pepper seedlings are sensitive to EC values higher than 1.5 dS m^{-1} (Luna-Fletes *et al.*, 2021; Liu *et al.*, 2023). Therefore, it is necessary to continue exploring different doses to obtain the optimum for this crop.

The only limitations in which the method may be compromised is the lack of electrical power for the operation of the electric motor and that does not allow the aeration to be carried out. Another limitation that can affect the results is excess rainfall. If the compost production is an outdoor area, and this is done in rainy seasons in an area with high rainfall, it can generate a problem of excess water and slow down the composting process.

CONCLUSIONS

Implementation of the ASP method to optimize the composting process showed that it is possible to generate composts from manures with good nutritional quality compared to those generated in the traditional way and with pH, OM and bulk density parameters within the standards established in the Official Mexican Norm (NOM). The increase in the nutritional values of the composts with the ASP method is due to the greater air input that increases microbial activity, raising the temperature of the composts and allowing the decomposition of the materials faster and in greater quantities than the traditional process. Further evaluation of different doses of composts generated by the ASP method for horticultural crops is needed.

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