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Application of poultry processing industry waste: A strategy for vegetation growth in degraded soil

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ABSTRACT

The disposal of poultry processing industry waste into the environment without proper care, can cause contamination. Agricultural monitored application is an alternative for disposal, considering its high amount of organic matter and its potential as a soil fertilizer. This study aimed to evaluate the potential of poultry processing industry waste to improve the conditions of a degraded soil from a desertification hotspot, contributing to leguminous tree seedlings growth. The study was carried out under greenhouse conditions in a randomized blocks design and a 4 × 2 factorial scheme with five replicates. The treatments featured four amounts of poultry processing industry waste (D_1 = control 0 kg ha^{-1}; D_2 = 1020.41 kg ha^{-1}; D_3 = 2040.82 kg ha^{-1}; D_4 = 4081.63 kg ha^{-1}) and two leguminous tree species (*Mimosa caesalpiniaefolia* Benth and *Leucaena leucocephala* (Lam.) de Wit). The poultry processing industry waste was composed of poultry blood, grease, excrements and substances from the digestive system. Plant height, biomass production, plant nutrient accumulation and soil organic carbon were measured forty days after waste application. Leguminous tree seedlings growth was increased by waste amounts, especially *M. caesalpiniaefolia* Benth, with height increment of 29.5 cm for the waste amount of 1625 kg ha^{-1}, and *L. leucocephala* (Lam.) de Wit, with maximum height increment of 20 cm for the waste amount of 3814.3 kg ha^{-1}. *M. caesalpiniaefolia* Benth had greater initial growth, as well as greater biomass and nutrient accumulation compared with *L. leucocephala* (Lam.) de Wit. However, belowground biomass was similar between the evaluated species, resulting in higher root/shoot ratio for *L. leucocephala* (Lam.) de Wit. Soil organic carbon did not show significant response to waste amounts, but it did to leguminous tree seedlings growth, especially *L. leucocephala* (Lam.) de Wit. Poultry processing industry waste contributes to leguminous tree seedlings growth, indicating that it can be part of a long-term strategy to increase soil organic carbon in degraded soil from a desertification hotspot.

1. Introduction

Poultry meat and eggs are important sources of protein for human nutrition in almost all countries in the world. For this reason, poultry sector continues to grow and industrialize in many parts of the globe (FAO, 2012). This sector influences the development of certain regions due to the effects of the production system (Montoya and Parré, 2000).

United States, China and Brazil are the largest poultry meat producers (Santos et al., 2013).

Poultry production has increased in developing countries and waste management is a critical factor for the sustainability of this activity. Waste materials of the processing poultry industry include offal (feathers, entrails and organs of slaughtered birds), processing wastewater and biosolids (Williams, 2011). These wastes contain high concentration of nitrogen, phosphorus, potassium, copper, and zinc (Terzich et al., 2000). Inappropriate disposal of poultry processing industry wastes may cause environmental problems related to contamination of superficial and ground waters, besides the impacts on air quality (Williams, 2011).

To avoid the aforementioned problems, management strategies for poultry processing industry waste have been studied (Endale et al., 2010; Watts et al., 2010; Bolan et al., 2010; Gayathri et al., 2011; Penn et al., 2011; Muhr et al., 2013). Studies on a diversity of waste aspects have been carried out, from generation and characterization to planning and implementation. However, in the topic of recycling and reuse, wastes have been used for fertilization, improving soil attributes, and contributing to plant growth (Bolan et al., 2010; Endale et al., 2010; Watts et al., 2010; Penn et al., 2011; Gayathri et al., 2011). This is a very interesting topic,

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since the waste is used without either environmental or health risks, once it is applied according to plant needs and the effects of its application are constantly monitored.

The use of organic wastes to fertilize soils in agricultural systems is an advantageous practice for soils in ordinary condition, as well as in degraded lands. In the first situation, waste use already represents an advantage just by the promotion of nutrient availability and reduction of mineral fertilizers dependence, allowing farmers to save money (Merson et al., 2010; De Bon et al., 2010). In the second situation, besides the advantage of nutrients availability with low costs, organic waste use may be an important strategy to improve soil attributes damaged by degradation. This improvement can be reached not only by nutrient availability, but also by increasing soil organic matter (Piotrowska et al., 2011; Trejo et al., 2012; Fenoll et al., 2011). Among the advantages obtained by soil organic matter increase, the improvement of soil structure, water storage and soil biological parameters have been mentioned.

Soils from desertification hotspots can be improved by the application of organic wastes (Nieto et al., 2010). The occurrence of desertification hotspots is related to the natural fragility of soils, associated with weather conditions and human interferences. Soil erosion rates and the organic matter content are used as indicators for land degradation and desertification monitoring (Kosmas et al., 2013). In order to reduce losses by erosion and increase soil organic matter in these areas, it is necessary to guarantee plant growth for soil protection and biomass production to increase contents of soil organic carbon. Leguminous tree species have a superior capacity to grow quickly in poor conditions of degraded soils (Chaer et al., 2011). However, if soil nutrient availability is too low, plant development will be limited. The application of organic wastes emerges as a strategy to improve previously soil condition in order to allow plant growth.

This study aimed to address the following research questions: Does the poultry processing industry waste improve leguminous tree seedlings growth? Does the poultry processing industry waste contribute more to one of the evaluated leguminous tree species? Does the poultry processing industry waste increase the organic carbon content of a soil from a desertification hotspot?

2. Material and methods

2.1. Characterization of the degraded soil

Soil sampling was performed in a rural settlement in the municipality of Irauçuba (Ceará State, Brazil). The soil in this area was previously managed with fire and overgrazing, showing by the time of soil collection visible signs of degradation represented by low organic matter contents and gully erosion (Fig. 1A and B).

One soil sample composed of 24 subsamples was collected for chemical and physical characterization. The collection of subsamples was randomized in the degraded area. The little organic debris was removed from soil superficial layer before subsamples collection. Soil pH was determined by the electrochemical measure of the effective concentration of H^+ ions in the soil solution using a combined electrode immersed in a 1:2.5 soil:water suspension (Embrapa, 2009). Soil total organic carbon (TOC) was determined by oxidation with potassium dichromate in a concentrated sulfuric medium (Yeomans and Bremner, 1988). The extraction of soil phosphorus (P) and potassium (K) was performed using Mehlich 1 solution ($0.05\ mol\ L^{-1}$ HCl + $0.0125\ mol\ L^{-1}$ H_2SO_4) (Mehlich, 1953). Phosphorus was quantified by colorimetry, while potassium was quantified by flame photometry. Calcium (Ca) and magnesium (Mg) were extracted using a 1 mol L^{-1} KCl solution and quantified by atomic absorption spectrometry. Potential acidity (H + Al) was extracted using a 0.5 mol L^{-1} Ca-acetate solution at pH 7. Analytical procedures for the determinations of P, K, Ca, Mg and H + Al followed the methods described in Embrapa (2009). Determinations of sum of bases (SB = K + Ca + Mg) and cation exchange capacity [CEC = SB + (H + Al)] were by calculation, according to the procedures described in Embrapa (2009).

Soil bulk density was determined by the cylinder method (Blake and Hartge, 1986). Contents of clay, silt, and sand were determined by the pipette method (Embrapa, 1997), which is based on the sedimentation speed of soil particles. In this method, the time is fixed for the vertical displacement of particles in soil suspension with water after the addition of a chemical dispersant. A suspension volume is collected with a pipette and then air-dried in order to determine clay content based on sample dry weight. For sand content determination, the remaining material is sieved, air-dried and then weighed. The silt fraction corresponds to the difference between the sum of clay and sand to complete 100%.

Results of soil chemical and physical characterization are shown in Table 1.

2.2. Characterization of poultry processing industry waste

Treated poultry waste from a processing industry located in the municipality of Aquiraz (Ceará State, Brazil) was used in this study. The waste generation occurs in distinct sectors of the processing industry: bleeding, plucking, evisceration, and carcass preparation.

(A) (B)

Fig. 1. General view (A) and gully erosion (B) in the soil sampling area.

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Table 1
Chemical and physical attributes of degraded soil before treatment application.

Attributes	Values
pH_{H2O}[a]	5.4
N (g kg^{-1})[b]	0.6
P (mg kg^{-1})[c]	4.13
K (mg kg^{-1})[c]	0.28
Ca ($cmol_c$ kg^{-1})[d]	2.6
Mg ($cmol_c$ kg^{-1})[d]	2.4
H + Al ($cmol_c$ kg^{-1})[e]	0.5
SB ($cmol_c$ kg^{-1})[f]	5.28
CEC ($cmol_c$ kg^{-1})[f g]	5.78
TOC (g kg^{-1})[h]	4.23
Sand (%)[i]	83.9
Silt (%)[i]	9.1
Clay (%)[i]	7.0
Soil bulk density (g cm^{-3})[j]	1.43

[a] 1:2.5 soil:water.
[b] Kjeldahl method.
[c] Phosphorus and potassium by Mehlich 1 extract.
[d] Calcium and magnesium by KCl extract.
[e] Potential acidity by 1 N Ca-acetate at pH 7.
[f] Sum of bases.
[g] Cation exchange capacity (SB + H + Al).
[h] Total organic carbon (Yeomans and Bremner, 1988).
[i] Pipette method (Embrapa, 1997).
[j] Volumetric ring method (Blake and Hartge, 1986).

The waste is composed of poultry blood, grease, excrements, and substances from the digestive system, having a high organic matter content.

After a preliminary treatment to remove raw solid materials, floating materials and setting mineral materials, the waste management in a poultry processing industry involves deposition in a drying bed, followed by disposal into the environment. The waste used in this study was collected in the drying bed and stored in bags with capacity for 50 kg, where it remained during three days for stabilization under aerobic conditions. Waste subsamples collection after stabilization constituted a composite sample for chemical analyses. According to procedures for organo-mineral fertilizers (Embrapa, 2009), the attributes analyzed in the sample were: pH (0.01 M $CaCl_2$); moisture content (60–65 °C); total nitrogen (N) by sample oxidation with perchloric acid and quantification by the Kjeldahl method; organic carbon (C) by humid oxidation with $K_2Cr_2O_7$ and concentrated H_2SO_4, and C/N ratio.

To determine organic carbon in the samples, the oxidizable matter was oxidized using a 0.2 mol L^{-1} $K_2Cr_2O_7$ solution. The remaining dichromate was titrated with ferrous sulphate. The titer was inversely related to the amount of C present in the soil sample. The equation used to calculate C content was:

$$\mathit{Organic\ carbon} = [(\mathrm{Vb} - \mathrm{Va}) * \mathrm{C} * 75]/\mathrm{m}$$

Where:

Vb = volume (ml) of the Fe^{2+} solution required to titrate the blank.

Va = volume (ml) of the Fe^{2+} solution required to titrate the sample.

C = Concentration of the Fe^{2+} solution (mol L^{-1}).

75 = Factor obtained from associations between $K_2Cr_2O_7$ reacting with 1.5 mol of organic carbon, carbon's molar mass , dilution factor and number of electrons involved in the reaction between Fe^{2+} and Cr_2O_4.

m = sample mass (g).

The poultry processing industry waste also was analyzed regarding total contents of phosphorus (P), potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), Manganese (Mn), and zinc (Zn). The digestion for total contents of P, K, Na, Ca, Mg, Cu, Fe, Mn, and Zn was performed by using nitric and perchloric acids (A.R.) in the proportion of 3:1. Phosphorus quantification was done by colorimetry; K and Na by fotometry and Ca, Mg, Cu, Fe, Mn, and Zn by atomic absorption spectrometry. All analytical procedures followed the methods described in Embrapa (2009). The results related to poultry processing industry waste are shown in Table 2.

2.3. Experiment

The experiment was perfomed in a glasshouse at the Soil Sciences Department of the Federal University of Ceará. Pots were filled with soil from a desertification hotspot located in the municipality of Irauçuba (Ceará State, Brazil). The experiment started in September 2013 and was carried out over a period of 40 days.

The experiment was installed in a randomized blocks design, in a 4 × 2 factorial scheme with five replicates, totalling 40 experimental units. Each experimental unit was composed of one pot containing one plant. The treatments applied featured four amounts of poultry processing industry waste (D_1 = control – 0 kg ha^{-1}; D_2 = 1020.41 kg ha^{-1}; D_3 = 2040.82 kg ha^{-1}; D_4 = 4081.63 kg ha^{-1}) and two leguminous tree species (*Mimosa caesalpiniaefolia* Benth and *Leucaena leucocephala* (Lam.) de Wit). *M. caesalpiniaefolia* Benth was selected to be studied because it is native from the semiarid region and adapted to dry conditions. *L. leucocephala* (Lam.) de Wit) was selected because it has shown good development in degraded substrates.

The dormancy of leguminous tree seeds was broken according to the procedures described by Passos et al. (2007) and Teles et al. (2000), in which seeds were immersed in a concentrated sulfuric acid solution (96–98%). Time of immersion was 06 min for *M. caesalpiniaefolia* Benth and 20 min for *L. leucocephala* (Lam.) de Wit. After immersion, seeds were washed with distilled water and placed in separate cells of the trail, filled with a mixture of sand and organic manure. The smaller seedlings were eliminated after germination, remaining only the vigorous ones, which were transplanted to 5-L pots after 15 days.

The amounts of poultry processing industry waste (D_1 = control – 0 kg ha^{-1}; D_2 = 1020.41 kg ha^{-1}; D_3 = 2040.82 kg ha^{-1}; D_4 = 4081.63 kg ha^{-1}) were based on the waste P content (19.6 g kg^{-1}), in order to add to the soil 0, 20, 40 and 80 kg ha^{-1} of P_2O_5. These amounts corresponded to 0; 2.55; 5.1; and 10.2 g of waste per

Table 2
Chemical and physical attributes of poultry processing industry waste (values expressed in wet basis).

Attributes	Values
pH $_{CaCl2}$[a]	5.94
Humidity (%)[b]	6.87
N (g kg^{-1})[c]	43.76
Organic carbon (g kg^{-1})[d]	4.61
C/N ratio	10.5/1
P (g kg^{-1})[e]	19.6
K (mg kg^{-1})[e]	6.0
Ca (g kg^{-1})[e]	45.1
Mg (g kg^{-1})[e]	1.7
Cu (mg kg^{-1})[e]	450.23
Fe (mg kg^{-1})[e]	1354.9
Mn (mg kg^{-1})[e]	94.9
Zn (mg kg^{-1})[e]	574.2
Na (mg kg^{-1})[e]	12.0

[a] pH – $CaCl_2$ 0.01 M.
[b] Gravimetric humidity (60–65 °C).
[c] Kjeldahl method.
[d] Wet oxidation by $K_2Cr_2O_7$.
[e] Phosphorus (P); potassium (K); sodium (Na); calcium (Ca); magnesium (Mg); copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn): nitric and chloridric acids.

pot, calculated by the relation between the soil volume of a 20-cm layer in one hectare and the volume of the pots (5 L).

The soil was sieved through a 2-mm mesh and mixed with the poultry processing industry waste to be added to each pot. After the transplantation of the seedlings, irrigation was performed over the 40-day period using distilled water, the amount of which was quantified by estimating the evaporated volume obtained by calculating the difference between the initial and final weights of the pots.

2.4. Evaluations

Plant height was measured with a ruler graduated in centimeters 40 days after seedlings transplantation. The height increment was obtained by the difference between the measurements at the beginning and at the end of the experiment. Plants were cut at the stem base 40 days after seedlings transplantation. Aboveground (leaves and stems) was separated from belowground (roots) and biomass and roots were washed with distilled water to ensure complete soil removal. Aboveground and belowground biomasses were placed in an oven at 65 °C until reaching constant mass and then weighed to determine dry matter.

Contents of N, P, K, Ca, Mg, Cu, Fe, Mn, and Zn were determined in the aboveground biomass, and N content was determined in the belowground biomass. Extracts for P, K, Ca, Mg, Cu, Fe, Mn, and Zn determination were obtained by nitroperchloric acid digestion prepared with HNO_3 65% (A.R.) and $HClO_4$ 72% (A.R.) in a proportion of 3:1. 8 ml of nitroperchloric acid were used for 500 mg of sample. The tubes containing samples and acid solutions were slowly heated until reaching 200 °C, remaining at this temperature for 3–4 h. The extract for N determination was obtained by sulfuric acid digestion, using 3 ml of H_2SO_4 98% and 1 ml of H_2O_2 30% for 100 mg of sample. The tubes containing samples and acid solutions were slowly heated until reaching 350 °C, remaining at this temperature until the obtention of a green viscous liquid. Ca, Mg, Cu, Fe, Mn, and Zn were quantified by atomic absorption spectrometry, while P was quantified by colorimetry, K by fotometry and N by titration. Laboratorial procedures followed the methods described in Embrapa (2009). Nutrient accumulation in both above and belowground biomasses of the leguminous trees was obtained by multiplying the values of dry matter by nutrient contents.

After plant cut, the soil from the pots was sampled, dried and analyzed for total organic carbon according to the method described by Yeomans and Bremner (1988).

2.5. Statistical analysis

Statistical analysis was performed using a Two-way ANOVA and the software SISVAR (Ferreira, 2000). Non-normal data were transformed $(\sqrt{x} + 0.5)$ before variance analysis. For significant differences, Tukey test (5% of probability) was applied to compare qualitative factors (tree species), while regression analysis was applied to evaluate quantitative factors (amounts of poultry processing industry waste).

3. Results

3.1. Plants height and biomass

Plant height was influenced by both plant species and poultry waste amounts. Height increment, aboveground biomass and belowground/aboveground ratio showed interaction between treatment factors (Table 3). By the time of plant height evaluation (40 days after seedlings transplantation), *M. caesalpiniaefolia* Benth seedlings were higher than the ones of *L. leucocephala* (Lam.) de Wit, having also greater values of height increment and aboveground biomass, resulting in lower belowground/aboveground ratio in comparison with *L. leucocephala* (Lam.) de Wit (Table 3).

In response to poultry waste amounts, *M. caesalpiniaefolia* Benth had height increment of 29.5 cm for the waste amount of 1625 kg ha^{-1}, representing a point where the height increase rate starts to stabilize (Fig. 2A). *L. leucocephala* (Lam.) had height increment of 20 cm for the waste amount of 3814.3 kg ha^{-1} (Fig. 2A). Despite the greater height increment observed for *M. caesalpiniaefolia* Benth, the height increment differences between waste amounts were more evident for *L. leucocephala* (Lam.) de Wit, especially from the waste amount of 2040.82 kg ha^{-1}. On the other hand, greater height increment obtained by *M. caesalpiniaefolia* Benth occurred in response to the waste amount of 1020.41 kg ha^{-1} (Fig. 2B).

Aboveground biomass was greater for *M. caesalpiniaefolia* Benth for the first three waste amounts (Fig. 3). However, from the third amount of poultry processing industry waste (2040.82 kg ha^{-1}) on, aboveground biomass was not significantly different between species . The poultry waste effect on the aboveground biomass of *M. caesalpiniaefolia* Benth was higher at the amount of 1020.41 kg ha^{-1}, while on *L. leucocephala* (Lam.) de Wit this effect was more evident at the highest poultry waste amount (4081.63 kg ha^{-1}).

3.2. Nutrients accumulation in plants

In the aboveground part of leguminous tree seedlings, macronutrient accumulation response was observed for plant species and poultry waste amounts (Table 4). The greatest macronutrient accumulation was observed for *M. caesalpiniaefolia* Benth (Table 4). Regarding the exchangeable bases, it is interesting to observe the increase in Ca and Na accumulation in response to poultry waste amounts (Fig. 4). N and P accumulation also increased with poultry waste amounts (Fig. 5A and B).

Table 3
Summary of ANOVA for leguminous trees growth parameters with *F*-values and significance symbols. Means of growth parameters for each leguminous tree.

Sources	Height	Height increment	Aboveground dry mass	Belowground dry mass	Root/shoot ratio
Leguminous Species	50.631**	62.211**	19.001**	0.223ns	33.569**
Waste rates	6.278**	10.193**	4.590**	2.290ns	6.360**
Leguminous Species *Waste rates	2.539ns	4.500*	3.017*	1.599ns	6.213**
Blocks	1.637ns	1.979ns	1.653ns	3.412ns	1.301ns
Coefficient of variation (%)	25.96	28.1	15.99	40.23	8.6
Species	cm		g plant^{-1}		
L. leucocephala	16.76b	12.58b	0.84b	0.28a	0.49a
M. caesalpiniaefolia	30.59a	26.15a	1.47a	0.30a	0.21b

**, * and ns: Significant at 1 and 5% of probability and non-significant, respectively.
Means followed by different small letters (a) and (b) within columns do differ at 5% of probability by Tukey test.

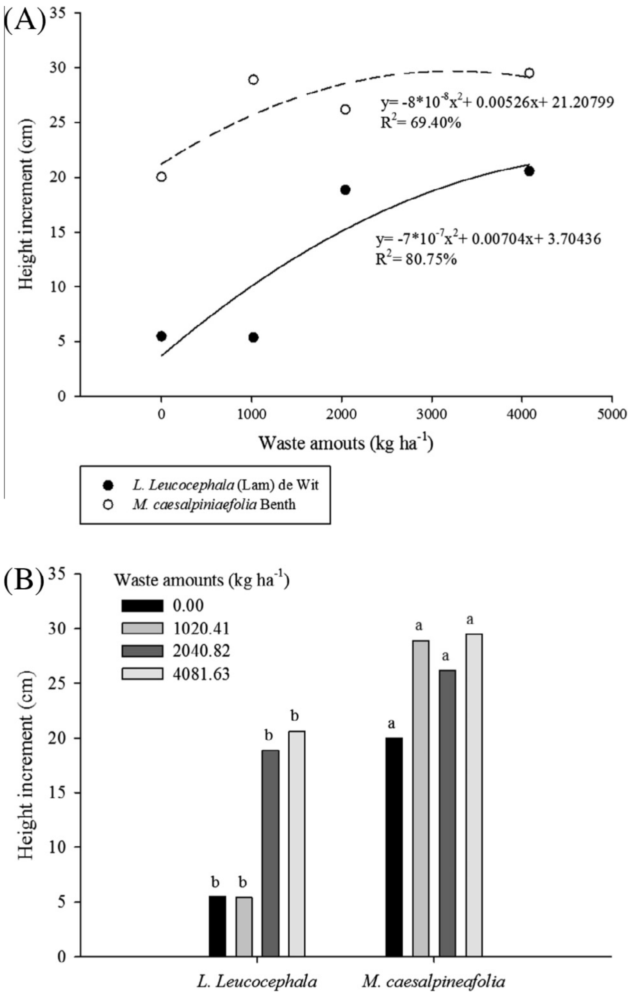

Fig. 2. Regression curve (A) and height increment of leguminous trees in response to waste amounts (B). In (B) small letters (a) and (b) compare height increment of the two species in each waste amount.

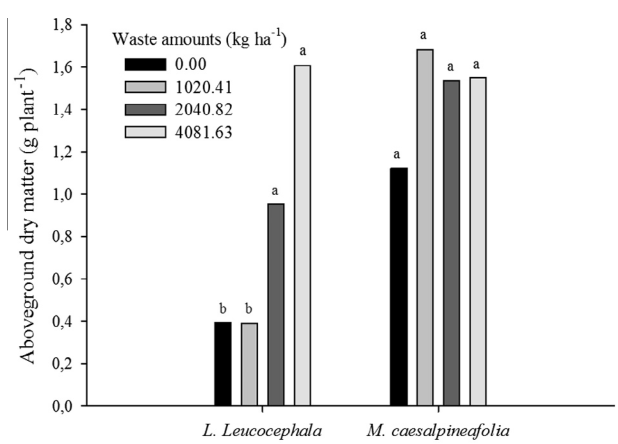

Fig. 3. Aboveground dry matter of leguminous trees in response to waste amounts.

There was interaction between leguminous tree species and poultry waste amounts regarding the response to micronutrient accumulation in aboveground parts, except for Cu. *M. caesalpiniaefolia* Benth also had greater accumulation of micronutrients than *L. leucocephala* (Lam.) de Wit, with exception for Zn, which was similar for both leguminous trees (Table 4).

In the belowground part of leguminous tree seedlings, only N accumulation was determined and it was not affected by treatments.

3.3. Soil organic carbon

The analysis of soil organic carbon revealed no significant response to poultry waste amounts. However, leguminous tree species promoted differences in this parameter, with greater content in soil under *L. leucocephala* (Lam.) de Wit (7.29 g kg^{-1}) in comparison with soil under *M. caesalpiniaefolia* Benth (4.93 g kg^{-1}) (Fig. 6).

4. Discussion

4.1. Plant height and biomass

The lower *L. leucocephala* (Lam.) de Wit height is explained by its slow initial growth and the fact that the plant concentrates most of its energy in the formation of the root system. For this reason, the recommendation to its establishment in the field is by seedlings, ensuring uniform and vigorous stands (Teles et al., 2000). Similar result of greater height for *M. caesalpiniaefolia* Benth was observed by Araújo (2012), evaluating leguminous tree species development in iron mine spoils amended with organic waste. The author found 31 cm of height for *M. caesalpiniaefolia* Benth 40 days after transplantation. In the present study, 98.5% of the height of *M. caesalpiniaefolia* Benth was obtained in less than half of the time after transplantation evaluated by Araújo (2012). This indicates the potential of poultry processing industry waste to contribute to the initial growth of *M. caesalpiniaefolia* Benth.

Plants height increased with poultry waste amounts, highlighting the positive effect of waste application. Other authors also observed increase of *M. caesalpiniaefolia* Benth height in response to waste or nutrient application (Barroso et al., 2000; Oliveira et al., 2012). Studies have shown poultry waste benefits in the development of other plant species, like maize and cotton (Endale et al., 2010; Gayathri et al., 2011).

The height increment of *M. caesalpiniaefolia* Benth was less responsive to poultry waste amounts in comparison with *L. leucocephala* (Lam.) de Wit. It can happen because *M. caesalpiniaefolia* Benth is native from the Brazilian semiarid region, while *L. leucocephala* (Lam.) de Wit is exotic. Probably, native species interacted with soil microorganisms that contribute more effectively to seedlings development than waste application. Studies have shown that local soil microbial communities have positive impact on the growth of native plant species (Bozzolo and Lipson, 2013).

M. caesalpiniaefolia Benth had greater aboveground biomass than *L. leucocephala* (Lam.) de Wit did, while their belowground biomasses were similar. It led to lower belowground/aboveground ratio, confirming the findings of Araújo and Costa (2013). The higher belowground/aboveground ratio of *L. leucocephala* (Lam.) de Wit is a favorable characteristic to grow in semiarid conditions, allowing it to save water through the reduction in leaf transpiration when compared with *M. caesalpiniaefolia* Benth, which has greater aboveground biomass. The success recovery of degraded areas in semiarid regions depends on, among other factors, a better choice of plant species regarding water use efficiency.

4.2. Nutrients accumulation in plants

M. caesalpiniaefolia Benth accumulated more nutrients in the aboveground part due to the high biomass production. Araújo and Costa (2013) observed the same trend, mentioning positive aspects of higher nutrient accumulation in aboveground, since

Table 4
Summary of ANOVA for the evaluated parameters with *F*-values and significance symbols. Nutrient accumulation in aboveground of *L. leucocephala* (Lam.) de Wit and *M. caesalpiniaefolia* Benth 40 days after waste application.

Sources	Cu	Fe	Mn	Zn	P	N	K	Na	Ca	Mg
Leguminous Species	55.495**	23.798**	19.851**	7.708**	9.974**	12.305**	5.213*	23.468**	39.9136**	24.055**
Waste rates	7.456**	0.113^{ns}	3.368*	8.195**	6.266**	4.687**	3.022*	7.418**	8.420**	7.588**
Leguminous Species *Waste rates	1.778^{ns}	4.304*	3.708*	6.099**	2.700^{ns}	2.660^{ns}	2.238^{ns}	2.493^{ns}	2.467^{ns}	3.054*
Blocks	2.507^{ns}	2.106^{ns}	0.349^{ns}	1.469^{ns}	2.527^{ns}	0.722^{ns}	0.742^{ns}	2.492^{ns}	2.292^{ns}	1.777^{ns}
Coefficient of variation (%)	24.08	31.71	25.21	30.12	30.62	26.55	25.56	23.91	23.23	21.38
Species	μg plant^{-1}					mg plant^{-1}				
L. leucocephala	16.72b	171.20b	118.30b	147.87a	31.30b	30.34b	1.66a	14.05b	10.22b	3.21b
M. caesalpiniaefolia	47.15a	453.15a	212.29a	194.81a	50.10a	47.32a	0.86b	26.09a	22.57a	5.88a

**, * and ns: Significant at 1 and 5% of probability and non-significant, respectively.
Means followed by different small letters (a) and (b) within columns do differ at 5% of probability by Tukey test.

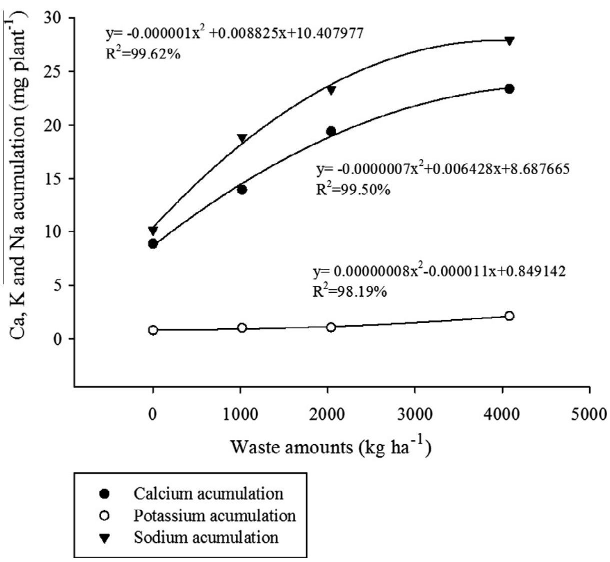

Fig. 4. Calcium, potassium, and sodium accumulation by leguminous trees in response to waste amounts.

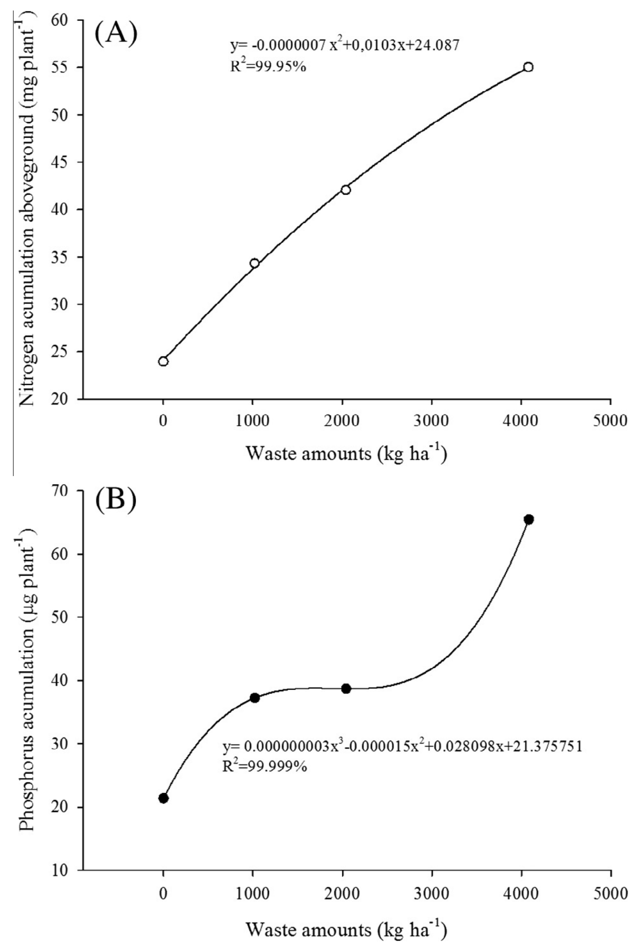

Fig. 5. Nitrogen (A) and phosphorus (B) accumulation in response to waste amounts.

elements accumulated in leaves and stems are subject to be mineralized, because dry matter becomes litter fractions, contributing mainly to N availability.

The explanation for the increase in accumulation of Ca, Na, N, and P is the high content of these elements in the poultry processing industry waste (Table 2). If compared with element contents in other organic residues, like animal dungs and vermicomposting (Raij et al., 1997; Yadav and Garg, 2011), poultry processing industry waste has the highest amount of the mentioned elements. High contents of N and P make poultry waste favorable for using in degraded land vegetation strategies, mainly for soils from desertification hotspots, because most of them are poor in nutrients. However, it is necessary to pay special attention to high amounts of Ca and Na, which can degrade even more the environment, increasing soil salinity. Nitrogen and phosphorus also deserve attention, because of their potential to pollute superficial and ground waters.

4.3. Soil organic carbon

Because poultry processing industry waste has high amount of organic carbon, soil organic carbon was expected to increase with waste amounts. The increase in soil organic carbon in response to organic waste application has been shown in other studies (Nieto et al., 2010; Odlare et al., 2011). However, in the present study soil organic carbon did not change in response to poultry waste amounts. In order to explain it, the characteristics of the organic residue must be taken into account. González-Ubierna et al. (2012) mentioned that it is not clear whether all organic amendments are suitable material for contributing to the pool of humic-like soil stable substances or whether they are consumed by soil microorganisms and released to the atmosphere as CO_2.

In this study, poultry waste was not composted before application, which may have caused rapid decomposition of readily decomposable organic compounds with production of CO_2 (Senesi, 1989). Probably, this rapid decomposition hides the direct effect of organic waste increasing soil organic carbon. However, nutrients availability was not compromised, because the waste had low C/N ratio, contributing to seedlings growth. In this sense,

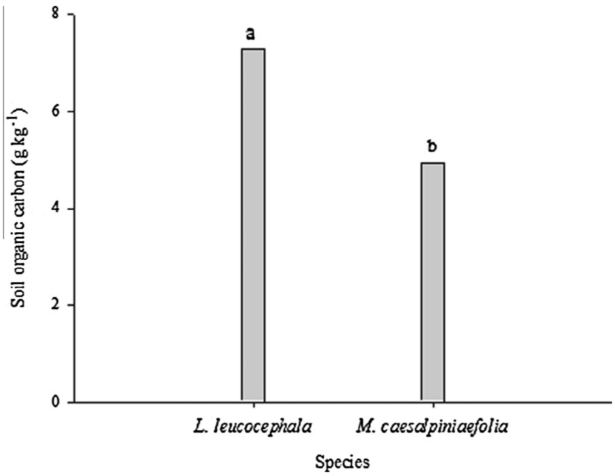

Fig. 6. Soil organic carbon in response to leguminous tree species.

the soil organic carbon response was due to leguminous tree species that, in turn, were affected by poultry waste.

5. Conclusion

Poultry processing industry waste contributes to leguminous tree seedlings growth and is required in small amounts by *M. caesalpiniaefolia* Benth, which had greater growth in comparison with *L. leucocephala* (Lam.) de Wit.

The waste amounts do not affect soil carbon contents directly, but it may be favorable in a long-term due to the improvement of the vegetation growth process.

However, the application of poultry processing industry waste on degraded soils needs to be monitored regarding both salinization and pollution risks.

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