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N. Ramdani[a], A. Hamou[a], A. Lousdad[b] & Y. Al-Douri[c]

[a] Department of Physics, Laboratory of Environmental Sciences Study and Materials (LESEM), Faculty of Sciences, University of Oran, Oran 31000, Algeria

[b] Mechanical Engineering Department, Laboratory Mechanics of Structures and Solids (LMSS), Faculty of Technology, University of Sidi Bel-Abbes, Sidi Bel-Abbes 22000, Algeria

[c] Institute of Nano Electronic Engineering, University Malaysia Perlis, 01000 Kangar, Perlis, Malaysia

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Physicochemical characterization of sewage sludge and green waste for agricultural utilization

N. Ramdani[a*], A. Hamou[a], A. Lousdad[b] and Y. Al-Douri[c]

[a]*Department of Physics, Laboratory of Environmental Sciences Study and Materials (LESEM), Faculty of Sciences, University of Oran, Oran 31000, Algeria;* [b]*Mechanical Engineering Department, Laboratory Mechanics of Structures and Solids (LMSS), Faculty of Technology, University of Sidi Bel-Abbes, Sidi Bel-Abbes 22000, Algeria;* [c]*Institute of Nano Electronic Engineering, University Malaysia Perlis, 01000 Kangar, Perlis, Malaysia*

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In order to valorize the organic wastes, a mixture composed of 60 kg of thick sewage sludge from a wastewater treatment plant, 30 kg of green wastes (made of 10 kg straw of wheat, 10 kg manure farm wastes, and 10 kg of dead leaves), and 10 kg of wood chips was prepared. The organic wastes were mixed and put into a wooden cubic composter having a volume of 1.5 m^3. Physicochemical analyses were made every 30 days for five months. The results of the analyses showed that the obtained compost had good physicochemical quality and can be used as an organic fertilizer. The main characteristics of this compost were distinguished by its pH from 7.4 to 7.8, with a ratio of organic matter of 40–42%. During composting, the humification process led to an increase in humic acids from 29.5 to 39.1 mg g^{-1}, a decrease in fulvic acids from 32.1 to 10.9 mg g^{-1}, and a global decomposition of hemicellulose, cellulose, and lignin. The obtained results show that a period of 150 days of composting gave a C/N ratio of 15.4. The total metal content in the final compost was much lower than the standard toxic levels for composts to be used as good soil fertilizers. The germination index for the two plants *Cicer arietinum* and *Hordeum vulgare* was 93% after the same period of composting, showing that the final compost was not phytotoxic. The study showed the possibility of valorization of the compost and its possible use in the domain of agriculture.

Keywords: sewage sludge; green waste; characterization; composting; valorization

1. Introduction

The necessity of preserving natural resources by optimizing their use by recycling and the valorization of the organic wastes is an interesting alternative. The estimated total organic waste in Algeria was more than 750 millions of tons in 2009.[1] Among the organic wastes is the residual sewage sludge generated from domestic wastewater treatment plants which are a source of rich organic matter with many elements easily assimilated by plants. Valorization of this sewage sludge, whose annual production in Algeria is estimated at more than 0.7 million tons, can contribute to ameliorating the physicochemical characteristics of the soils and reducing the pollution of soils due to chemical fertilizers. Sewage sludge from the wastewater treatment plant is richer in various elements and can contribute to the rehabilitation of nutritive reserves of soils exploited by inconvenient cultural techniques.[2]

Many techniques exist to eliminate this sewage sludge such as dumping, also called storage, which is inefficient and forbidden in many countries.[3] The incineration technique has a high cost and presents a risk related to the impact of toxic gases on the environment such as the dioxin.[4] On the other hand, many techniques are used for environmental protection, risk minimization, and ease of sewage sludge management. To name a few, these processes aim at improving biodegradability, achieving nutrient balance, and reaching sanitized and stabilized sewage.[5–7]

Energetic valorizations such as the production of biogas as a source of heat and electricity as well as biological or agricultural valorization, which is the production of fertilizers and composts, constitute green technologies. These latter techniques allow the transformation of sewage sludge into high-value products and minimize the risks of pollution.[8,9] The recycling or agricultural valorization of sewage sludge after composting contributes to the reintegration of mineral and organic elements in the soils, resembling closer to natural cycles.[10] However, application of the obtained composts cannot be carried out without the knowledge of their hygienic state, their stabilization, and maturity. Moreover, the composts of sewage sludge must be exempt of phytotoxicity with low concentrations of heavy metals (Cu, Zn, Cd, Hg, Cr, etc.), meeting the standard levels.[11]

The use of dehydrated sewage sludge in agriculture has many advantages since it contains a significant quantity of nitrogen, phosphorous, and oligo-elements. It has been recommended to improve the physicochemical properties

*Corresponding author. Email: nadia_ramdani@ymail.com

of soils.[12,13] Its application as bio-fertilizer added to the available green wastes has improved considerably the growth of plants.[14]

The decomposition of organic matter is an oxidation reaction by microorganisms before the humus stage. There is a production of polysaccharides which contributes to the structural stability of the soil. The organic matter improves soil resistance to draught and increases its retention capability. The liberation by transformation of an organic matter of nitrogen (N_2), sulphur (S), magnesium (Mg), and other oligo-elements is another benefit of the valorization of this sewage sludge. The application of composts of various wastes such as compost of leaves [15] and compost of agro-industrial wastes [16] has allowed improving the physical properties of soils as well as the performance of plants. According to the Direction of Water and Diversity (DEB) [17] the production of sewage sludge from treated domestic wastewater is estimated at 20 kg of dry matter per person and per year. The use of sewage sludge for agriculture as compost reached 73% in 2008. The incinerated quantity reached 18% and 9% as CTL (Centre of Technical Landfill) buried quantity.

The main problem of valorization of sewage sludge from domestic wastewater treatment stations is their low capacity of desegregation and incorporation into soils. This requires incorporating other green wastes in order to improve the process of decomposition and composting. The maturity of the compost remains a parameter to be discussed. Many authors have suggested the use of different maturity indices (ratio C/N, humification indices, germination indices, and the test of phytotoxicity) in order to adopt a type of compost easily to valorize.[18–21]

The present work focuses on the physicochemical and microbiological characterization of this co-composting and aims to evaluate the possibilities to use it as an agricultural bio-fertilizer through the study of the behaviour of two plants, namely barley (*Hordeum vulgare*) and chick pea (*Cicer arietinum*), a legume .

2. Equipments and methods

The valorization of sewage sludge is carried out by mixing it with green wastes. A mixture composed of 60 kg of thick sewage sludge from wastewater treatment plant, 30 kg of green wastes (10 kg straw of wheat, 10 kg of manure farm waste, and 10 kg of dead leaves), and 10 kg of resinous wood chips was prepared. These ratios were used since the residual sewage sludge is richer in organic matter such as nitrogen, phosphorous, and oligo-elements. This compost requires the addition of a constructing carbonized substance: the green waste. Composting allows the valorization of these two bio-wastes to produce a stable product.

The mixture of these organic wastes was put into a wooden cubic composter having a volume of 1.5 m^3 for a period of 150 days. Physicochemical analyses were carried out every 30 days for 5 months in order to identify the lap of time that allows obtaining a compost with good physicochemical quality that can be used as an organic fertilizer. To confirm the positive impact of this compost, an experiment was carried out based on the incorporation of different ratios of the compost (25%, 50% and 75%) in a clay –sand texture soil, with barley culture and a leguminous chick pea for a 60-day period. Two impact indicators of the effect of the compost were chosen: the biomass of the aired and rooted parts at the end of the experiment.

A representative sample was taken from the homogenized compost pile for the heavy metals and other analyses. Subsamples of 250 g each were taken from 10 different points of the compost (bottom, surface, side, and centre) at each stage of composting (0 day, 30, 60, 90, 120, and 150 days of composting).

The samples of the compost used for this physicochemical analysis were sifted to 20 mm and crushed to 1 mm before each analysis. Temperature was measured with an electronic thermometer linked to a probe inside the compost during the composting process. Temperatures were taken every two days. Immediately after sampling, a part of each of the already sifted compost was dried in a chamber at 105°C. This portion of the sample was weighted before and after drying. The drying phase was considered complete when the mass remained constant for about 48 hours.

pH of the compost was measured by mixing 10 g of the compost in 100 mL of bi-distilled water. Electrical conductivity for the same condition, proportion, and volume as for the pH was also determined. Proportioning of the total organic carbon, referred to as TOC, was made using the method of ANNE [22] and proportioning of nitrogen was made using the Kjeldahl method. Proportioning of ammonium ions NH_4^+ was done by distillation in an alkali environment, and nitrate NO_3^- was obtained by reduction using the alloy technique of Devarda.[18] Ash content was determined after calcinations at 550°C. Decomposition (Dec) was calculated according to the following formula [23]:

$$\text{Dec}\ \% = 100 \times \left[\frac{(A_f - A_i)}{A_f} \times (100 - A_i)\right] \times 100, \quad (1)$$

where A_f is final ash and A_i is initial ash.

Heavy metals analysis was carried out. Total Zn, Cu, Pb, Ni, and Cd were analysed by using the method of French Association of Normalizations.[24] One gram of each sample was mineralized for 4 h at 550°C and then dissolved in 5 mL of hydrofluoric acid. The solution obtained was evaporated to dryness and the residue was then dissolved with concentrated HNO_3/HCl (1:1) solution and the acid solution was diluted for analysis. Physicochemical characteristics of the components used for composting are given in Table 1.

Table 1. Physicochemical characteristics of the sewage sludge and green waste used for composting.

Parameters	Sewage sludge	Green waste
pH	7.55 ± 0.01	7.02 ± 0.02
Moisture (%)	72.1 ± 0.3	40.1 ± 0.1
Total Kjeldahl nitrogen ($g\ kg^{-1}$)	13 ± 0.1	14.1 ± 0.05
Total organic carbon ($g\ kg^{-1}$)	347.5 ± 0.6	462.3 ± 0.3
C/N ratio	26.7 ± 5.3	32.7 ± 4.2
Ash ($g\ kg^{-1}$)	305 ± 0.05	81.7 ± 0.01

Note: Results expressed in $g\ kg^{-1}$ of dry matter.

2.1. Extraction and assay of humic substances

Humic acids (HAs) and fulvic acids (FAs) were extracted by shaking a rotating evaporator containing 10 g of compost added to 100 ml of NaOH 0.1 M in 250 ml Erlenmeyer bowls for 2 hours. This soluble fraction in alkaline environment (HA + FA) was recovered by centrifugation at 2500 rpm during 25 min. The solution was acidified at pH 1 by adding chloride acid (HCl 6M) after one night at a temperature of +4°C. The soluble fraction in the FA environment was separated from the insoluble fraction in the HA environment by centrifugation at 10,000 rpm during 10 min. The two fractions were dried in an oven at 105°C during 48 hours.[25]

2.2. Extraction of lignin

The fractioning made is adapted to the method of Lam et al.[26] The lignin and the hemicelluloses are extracted from the dissolution in a mixture of acetic acid–formic acid–water (50–30–20 v/v). The ratio of solid/liquid is 1/12 or 60 ml for 5 g of compost. The first step consists of impregnation during 30 min at 50°C in the reactive environment and then for 1 hour at 107°C (azeotropic boiling point of the acid/water mixture). The soluble fraction is then recovered by filtration (Whatman glass fibre filter). The acids used are separated by distillation from the residual made of lignin and hemicelluloses. The addition of water to this residual leads to the precipitation of the lignin, whereas the hemicelluloses stay in the solution. Centrifugation for 30 min at 10,000 rpm allows the separation of the two biopolymers. The lignin is then washed with bi-distilled water up to a neutral pH and then dried at 105°C for 48 hours.

2.3. Microbiological analyses

All the samples of the compost used for microbiological analyses are sifted to 20 mm and kept at 4°C before the analysis. The following groups were quantified for bacterial loads: (i) total aerobic mesophile (TAM), (ii) actinomycete, (iii) sporulating aerobic bacilli, (iv) yeasts and moulds, and (v) Salmonella sp.

Extraction of the microorganisms was performed from 5 g of compost, 45 mL of 0.1 M tampon phosphate, pH 7, and 0.05% Tween 80. The mixture was homogenized for 30 min at a temperature of 30°C. Serial dilutions were then made from sterile physiological water (NaCl 0.85%). The counting and dilutions in the series of 10^{-2}, 10^{-5}, and 10^{-6} are used for sowing in environments in Petri dishes using 1 mL of each dilution. The microorganisms were counted after sowing in petri dishes and incubation.

2.4. Germination index

The germination index was used to determine the inhibitory potential of the compost water extract. Seed germination test was carried out with Chinese cabbage using the compost substrate extract. Two grams of oven-dried compost was placed in a test tube with a screw cap and 20 mL of distilled water was added; the tube was then placed in an electric rotator and homogenized at 125 rpm for 1 hour. The supernatant was decanted and centrifuged at 10,000 rpm for 10 min and filtered through Whatman filtre paper. In all, 2 mL of filtrate was diluted in 1 mL of distilled water and sprayed over a sheet of filter paper kept inside the petri dish. Ten seeds of Chinese cabbage were then placed on the filter paper; another filter paper was moistened with 3 mL distilled water and 10 seeds were planted, and used as a control. The percentage of germination was measured after incubating the covered petri dishes in the dark at 28°C for 4 days.[18]

3. Results and discussion

3.1. The composting process

Seven analyses made on 20 parameters were carried out every 30 days from 0 to 150 days (T_0, T_{30}, T_{60}, T_{90}, T_{120}, and T_{150}). The analyses show an evolution of the different parameters and allow the identification of the best composting duration for obtaining better and interesting characteristics as shown in Table 2.

The variation in temperature recorded during the process (as shown in Figure 1) was typical of a two-phase composting process.[27,28] The initial stabilization phase was characterized by an increase in temperature, which reaches 69°C after a period of four days corresponding to the degradation of simple organic compounds. Then during the maturation phase, the temperature decreases progressively until an ambient temperature of 27°C, corresponding to the degradation of lignin–cellulose molecules. In other works, certain authors had suggested that the temperature could be considered as a good indicator at the end of the bio-oxidation phase, which is in good agreement with the observations of [29,30].

Table 2. Monthly follow-up of the compost physicochemical characteristics.

Properties	0 day	30 days	60 days	90 days	120 days	150 days
Moisture	53.8 ± 0.3	42.2 ± 0.2	39.4 ± 0.1	36.7 ± 0.1	35.2 ± 0.05	33.1 ± 0.2
pH	7.4 ± 0.05	7.3 ± 0.1	7.1 ± 0.1	7.6 ± 0.1	7.4 ± 0.2	7.8 ± 0.3
E.C (mS cm^{-1})	2.2 ± 0.1	1.8 ± 0.1	1.8 ± 0.05	1.8 ± 0.05	1.7 ± 0.1	1.8 ± 0.05
TOC (%)	35.5 ± 0.6	36.6 ± 0.1	41 ± 1.09	42 ± 1	35.2 ± 0.1	29.3 ± 0.1
TKN (%)	1.3 ± 0.1	1.4 ± 0.2	1.7 ± 0.05	1.9 ± 0.1	1.9 ± 0.3	1.9 ± 0.2
Ash (g kg^{-1})	32.8 ± 0.2	34.3 ± 1.02	36.3 ± 2.2	42.4 ± 0.5	46.2 ± 0.4	50.5 ± 1.1
C/N	27.3	26.1	24.5	22.7	18.7	15.4
Dec (%)	–	6.5	14.3	33.6	43.6	62.1
$N-NH_4^+$ (mg g^{-1})	2.5 ± 0.1	2.3 ± 0.1	2.6 ± 0.1	1.9 ± 0.1	1.3 ± 0.1	1.2 ± 0.1
$N-NO_3^-$ (mg g^{-1})	2.7 ± 0.1	2.5 ± 0.05	1.5 ± 0.1	1.6 ± 0.3	0.9 ± 0.2	0.6 ± 0.2
Mg total (g kg^{-1})	2.5 ± 0.1	2.6 ± 0.05	2.8 ± 0.1	2.8 ± 0.3	3.1 ± 0.2	3.5 ± 0.2
K total (g kg^{-1})	13.6 ± 0.1	9.9 ± 0.1	8.7 ± 0.2	8.7 ± 0.2	9.7 ± 0.5	9.6 ± 0.1
P total (g kg^{-1})	2.3 ± 0.1	2.2 ± 0.05	2.5 ± 0.1	1.9 ± 0.05	1.9 ± 0.1	2.1 ± 0.2
Mn total (mg kg^{-1})	48.6 ± 0.05	50.6 ± 0.5	50.6 ± 0.5	78.8 ± 0.6	79.8 ± 2	60.3 ± 0.8
Fe total (mg kg^{-1})	4875 ± 3.6	4777 ± 2.6	3058 ± 1.5	3703 ± 1.5	4057 ± 0.5	4464 ± 1
HAs (g kg^{-1}dry matter)	29.5 ± 1.3	30.6 ± 0.5	36.5 ± 0.6	39.3 ± 0.6	40.6 ± 0.4	39.9 ± 0.7
FAs (g kg^{-1}dry matter)	32.1 ± 1	23.2 ± 1.4	23.8 ± 2.05	17.7 ± 1.02	11.3 ± 0.4	11.2 ± 0.3
Lignin (g kg^{-1})	305.8 ± 1	287.4 ± 4.5	298.7 ± 0.3	275.6 ± 3.7	271.1 ± 0.5	270 ± 1
Cellulose (g kg^{-1})	74.5 ± 1.3	68 ± 1	52.4 ± 0.6	54 ± 2	46.1 ± 0.6	45.1 ± 0.3
Hemicellulose (g kg^{-1})	132.1 ± 1.9	131.3 ± 0.3	120.2 ± 1.2	78 ± 1.7	67.3 ± 1.3	66.1 ± 0.6

Note: E.C, Electrical conductivity; TOC, total organic carbon; TKN, total kjelahl nitrogen; Dec %, degree of decomposition.

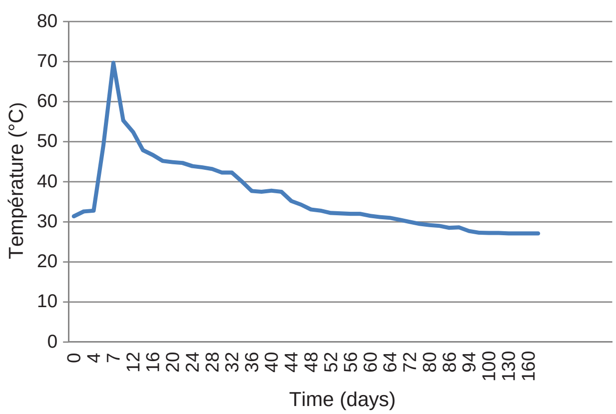

Figure 1. Variation in temperature during composting of sewage sludge and green waste.

According to [31], the measure of temperature is an indirect measure of the degradation intensities. During the humification process, the pH has slightly increased from 7.4 to 7.8. The disappearance of fat acids can explain the increase in pH during the composting process. Cayuela et al. had also observed a similar increase in pH (from 7 to 9) during the composting of industrial waste of olives. The waste of olives contains an important part of lipids and free organic acids.[32]

Tang et al. [33] have suggested that the released ammonia ions NH_4^+ during the process contribute to the increase in pH. The conductivity of the compost is highly dependent on its contained nutriments. However, a decrease in conductivity from 2.2 to 1.8 mS cm^{-1} after a period of 150 days was noticed. It was observed that the final compost does not overrun the salinity limit value of 3 mS cm^{-1} to be used as a good fertilizer.[34] The conductivity is very variable according to the compost; even it has a natural tendency to diminish with the progression of maturity.[35]

After a period of 150 days, the C/N ratio varies from 27.3 to 15.4 and the quantity of Ash from 6.5 to 62.1 g kg^{-1}, which reflects microbial decomposition of the organic matter and stabilization during the composting. The first phase of the decrease in organic matter can be attributed to an important degradation and mineralization of organic matter for a period between 0 and 50 days. The second phase is characterized by the stabilization of the two parameters, indicating a retardation of the mineralization and the beginning of the maturation phase. The organic nitrogen presents an increase in proportions of 1.3% and 1.9% for dry matter for a period from 0 to 150 days, respectively, as given in Table 2. This effect is due to its concentration generated by the high degradation of carbonized compounds reducing then the total mass of the compost.[36]

The organic and mineral nitrogen N with respect to the dry mass of the initial mixture decreases during the composting. As indicated in many investigations,[37,38] this decrease is related to the degree of maturity, which is a preponderant factor. A great part of the organic matters in the initial mixture is mineralized during the composting process. The residual organic matters are transformed into other organic matter with respect to humic substances (HS) produced by the humification process.[39] After a period of 150 days, the decomposition of the mixture reached a proportion of C/N ratio of 15.4. A slight acidification of the mixture during the first 10 days is the combined result of bio-acid production during composting and the production of carbon dioxide CO_2 during the aerobic decomposition of the organic matter. We assume that this phenomenon is assimilated as the production of acid due to incomplete oxidation. This is a sign of poor oxygenation due to the lack of pile turning for 10 days, which is necessary to maintain the aerobic conditions, as highlighted by [40].

The decrease in the concentration of nitrates from 2.7 to 0.6 mg g^{-1} is related to the nitrification process during the composting as indicated in Table 2. Inorganic nitrogen. $N - NH_4^+$ and $N - NO_3^-$ are generally affected by the action of proteolytic bacteria whose one part is incorporated in the stable organic forms such as amid heterocyclic nitrogen. The organic matter is decomposed and then transformed to stable humic compounds.[41] The HS have the capability of interacting with metallic ions to stabilize the pH and to act as a potential source of nutritive substances for plants. The rest of the process is distinguished by a phase of stabilization showing a retardation of the mineralization and indicates the beginning of the maturation phase according to many studies.[37,38] This diminution is related to the degree of maturity. Huang et al. [42] have reported that the modifications of the C/N ratio reflect the decomposition and stability of organic matters, which are confirmed by the obtained results shown in Table 2.

After 150 days, biodegradation reached 39.5%, 50%, and 12%, respectively, for cellulose, hemicellulose, and lignin. This is due to the rapid use by microorganisms of the carbohydrate oligomers released during the degradation of cellulose as a source of energy.[43] The degradation of cellulose was in the range of 74.5 and 45.1 g kg^{-1}.

This can be due to the inhibition of the activity of the microorganisms by high temperatures, which largely exceeded the threshold of 57°C,[44] and/or by the high ammonium content of the initial mixture.[45,43]

Chemical fractioning of the lignin slightly decreased from 305.8 to 265.1 g kg^{-1}, which confirms the resistance of the compound to biodegradation by undergoing a partial biotransformation.[46] This decrease has been linked to the increase in HA.

Hemicellulose is the component that had undergone the most important degradation. According to [47], xylans and other hemicellulose components tend to be degraded more easily than cellulose components or lignin. However, the low rates of hemicellulose and cellulose decomposition, at the beginning of the composting cycle (t_{60}), varied from132.1 to 66.1 g kg^{-1} and 74.5 to 45.1 g kg^{-1}, respectively. According to the results obtained, the low rates of cellulose and hemicellulose decomposition, observed at the beginning of the composting process is due to inhibition of the activity of the microorganisms involved by high temperatures. The total P, K, Mg, Fe, and Mn were more important to use this material as mineral fertilizers.[34] Therefore, application of the material will increase the stable organic N and humic carbon content and improve the amount of mineral elements necessary for plant growth.

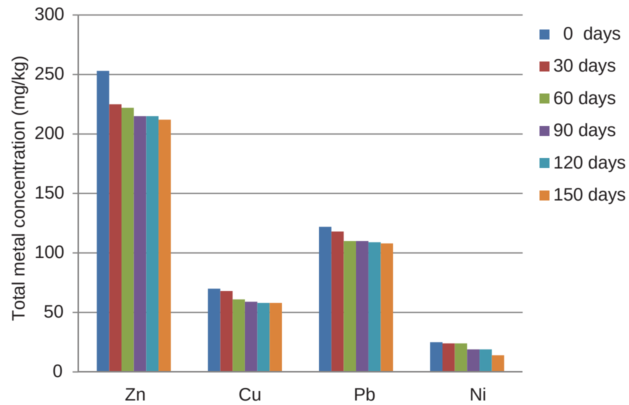

Figure 2. Total amount of heavy metals during composting of sewage sludge and green waste.

3.2. *Heavy metals content of compost*

Composting can concentrate or dilute heavy metals present in the sludge.[48] Lowering the amount of heavy metal depends on metal loss through leaching. The increase in metal level is due to weight loss in the course of composting following organic matter decomposition, release of carbon dioxide and water and the mineralization processes.[49]

Figure 2 shows the total concentration of metals (Zn, Cu, Pb, and Ni) during composting. The order of total metal content in the final composted sewage sludge and green waste was Zn > Cu > Pb > Ni. During composting, all total metal content decreased. This could be explained by metal loss through leaching in the course of composting. This loss mainly occurred during the thermophilic phase, which could be related to metal release from decomposed organic matter and change in other oxidic and anionic conditions in the medium, increasing so too the solubility of metals.[34,37,48]

Determination of the total content of heavy metals in the elaborated compost showed values significantly lower than those obtained for composts authorized for agricultural use by the Canadian limits standards which classify them as excellent composts as shown in Table 3. However, knowledge of the total content of heavy metals remains insufficient to estimate the mobility risk and metal bioavailability for plants. The results of the metal analysis of the compost at different stages of composting show that the main part of the metal elements concentrated in the most resistant fractions is either not or weakly bioavailable to plants. Only a weak proportion represents the unstable fraction that is easily bioavailable (exchangeable + soluble).

Table 3. Total heavy metal contents in the final compost (on the 150th day) and allowable limit for different classes of composts. (*According to Canadian limit* (*CCME 1995*) *results expressed in dry basis*).

Heavy metal	Final compost content (mg kg^{-1} dry wt)	Allowable limit (mg kg^{-1} dry wt) Class A	Allowable limit (mg kg^{-1} dry wt) Class B
Zn	212	500	1850
Cu	58	100	757
Pb	108	150	500
Ni	14	62	180
Cd	nd[a]	3	20

Notes: Class A compost (which has no restrictions in use). Class B compost (which can be used on forest lands and roadsides and for other landscaping purposes).
[a]nd, non-dectectable.

3.3. *Humification during the composting*

The results obtained show that the humification process during the stabilization of organic matters corresponds partially to the transformation of lignin into HAs. On the one hand, the concentration of HAs increases from 29.5 to 39.1 mg g^{-1}; on the other hand, the concentration of the FAs varies from 32.1 and 10.9 mg g^{-1} between the period from 0 to 150 days of composting, showing a great increase in the ratio of HA/FA. Several studies have shown that the increase in HA is an indicator of the degree of humification of organic matters and thus of the degree of maturity of composts.[50,51] Huang et al. [51] had also explained that the humification of organic matters takes place mainly through the HA fraction and less through FA fraction. Thus, the ratio HA/FA (humic acids/fulvic acids) is then an indicator of humification processes whereas a maturity index.

According to [52] the increase in HA/FA ratio comes from the formation of HA by polymerization of the FA or by the degradation of non-HS of the FA fraction followed by the formation of HA poly-condensed humic structures.

In aqueous compost samples, a germination index of *C. arietinum* and *H. vulgare* of more than 50%, reaching 93% after a period of 150 days of composting was observed. A germination index greater than 50% indicates that the maturity is sufficient.[18,53] Phytotoxic compounds such as acetic, propionic, butyric, and iso-butyric acids cannot be metabolized, and thus inhibit germination.[54]

The analysis of the obtained results confirms the important fluctuation in the physiochemical parameters during the first 90 days, followed by a certain stabilization beginning at the 150th day as given in Table 2. A certain stabilization of the main physiochemical parameters is observed between the 120th day and the 150th day and seems to be the compost looked for allowing its use as organic amendment in vegetal production.

3.4. *Microbiological quality of the compost*

During composting the microbial activities are diverse.[29,55] According to the results obtained from our microbial analyses, the following observations can be made: The microbial analyses of the initial mixture (sewage sludge/green waste) have shown that the results of the biomass germs were as follows: TAM: (5.8×10^6 CFU g^{-1} of fresh compost), bacilli: (4.4×10^6 CFU g^{-1} volume of fresh compost), yeasts and moulds: (2.7×10^6 CFU g^{-1} of fresh compost), and actinomycetes (3.2×10^4 CFU g^{-1} volume of fresh compost), as stated in Table 4. The values seem very important in the beginning of the composting cycle. The decrease in this biomass disappears during a high temperature treatment during the thermophile cycle.

The determination of Salmonella sp. was only qualitative (presence or absence), while they were present only at the beginning of the cycle. Then they underwent a complete inhibition at the end of the cycle. Their microbial density is significantly reduced after a period of 150 days of composting and reached 3.5×10^2 of bacilli and < 10 CFU g^{-1} of TAM, yeasts, and moulds, and 1.1×10^2 of actinomycetes. This decrease can be attributed to the lack of nutriments due to the elevation of temperature during the thermogenic phase (69°C during a period of 4 days). At this temperature the total pathogenic agents and nematodes are eliminated.[56,57] The purulent aerobic bacteria (bacilli) are very active at a temperature range of 60–65°C. The temperature cannot exceed 75°C. The main characteristics are presented in Table 4. Direct use of sewage sludge is limited by the presence pathogenic agents, by the fermentation of unstable organic matter, and by the presence of organic and inorganic pollutants that it contains.[56,58]

Composting is considered as a good pretreatment to overcome these problems.[59,60] The reached elevated temperatures of 50–70°C destroy almost all the pathogenic germs.[57]

3.5. *The effect of the combined compost on the H. vulgare (barley) and C. arietinum (chick pea)*

In order to confirm the impact of the obtained compost at the end of 150 days on soil fertility, an experiment based on the culture of barley (*H. vulgare*) and chick pea (*C. arietinum*) was carried out for 60 days. The best indicator for the

Table 4. Evolution of the concentrations of the microorganisms during composting.

Samples	Yeasts and moulds (CFU g^{-1})	Total aerobic mesophiles (CFU g^{-1})	Sporulating aerobic bacilli (CFU g^{-1})	Actinomycetes (CFU g^{-1})	Salmonella Sp. (CFU g^{-1})
T0	2.7×10^6	5.8×10^6	4.4×10^6	3.2×10^4	Presence
T30	5.6×10^6	4.6×10^6	5.6×10^4	5.7×10^4	Presence
T60	5.2×10^5	9.9×10^5	5.5×10^5	1.8×10^6	Absent
T90	4.1×10^5	2.1×10^4	2.9×10^3	4.4×10^5	Absent
T120	< 10	< 10	5.2×10^2	6.9×10^3	Absent
T150	< 10	< 10	3.5×10^2	1.1×10^2	Absent

Note: CFU, colony formed units g^{-1} of fresh material.

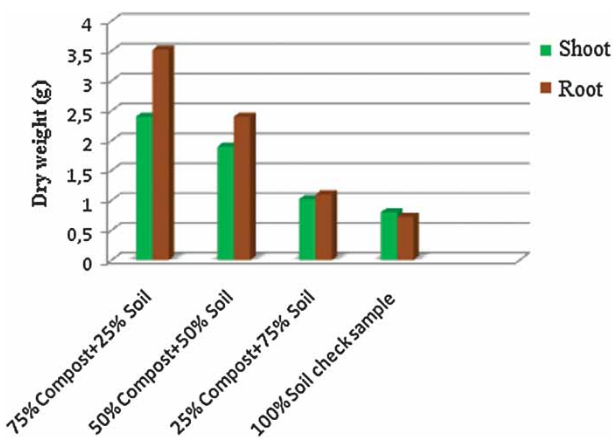

Figure 3. Effect of addition of compost on *H. vulgare* development.

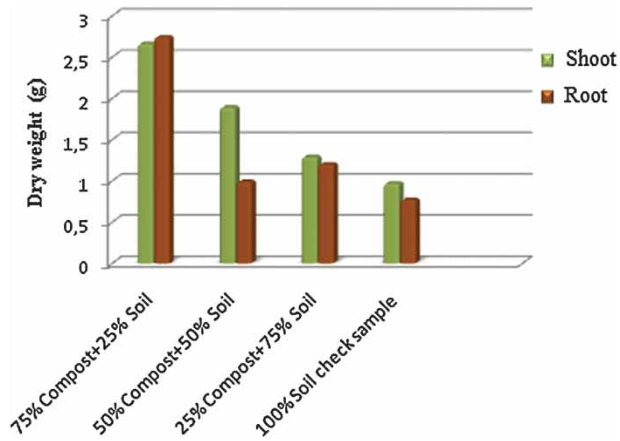

Figure 4. Effect of addition of compost on *C. arietinum* development.

appreciation of comparative results in such studies remains the dry biomass.

In order to estimate the value of compost fertility and quantify its impact on soil and vegetal products, experiments were carried out in a plastic greenhouse. These experiments were conducted on sandy soil (Table 5) using tests on two crops, namely *H. vulgare* and *C. arietinum*.

For each plant three compost amended pots with different concentrations (25%, 50%, and 75%) and one check sample were elaborated. Five grains per pot were seeded, irrigated, and regularly followed up to maintain 80% humidity. Three trials were made for each category. After 60 days of development and growth, the plants were taken out of the pots, and the root and shoot of each one were separated and weighted. They were dried at 70°C for 72 h in order to determine their dry weight.

3.5.1. *Behaviour of H. vulgare and C. arietinum*

The behaviour of the two plants was investigated. The obtained results after 60 days of culture are shown in Figure 3. The average increase in biomass with respect to the control sample is shown in Figure 4. One can note that the higher the percentage of addition of the compost, the higher the significant increase in the dry biomass of the two plants.

3.5.1.1. Response of H. vulgare. The total dry biomass increases proportionally to the ratio of the compost added to the soil of 2.12, 4.30, and 5.92 g for 25%, 50%, and 75% in volume, respectively, of compost addition to the soil. The total dry biomass (root and shoot) of the soil control sample is only 1.12 g. For the increase in height, the same observations are made since the average growth in height is 3.58, 1.40, and 3.62 cm. It is worth noting that the best response is obtained at a ratio of 25%, as shown in Figure 3.

3.5.1.2. Behaviour of C. arietinum. The behaviour of *C. arietinum* depends on the ratio of compost additive of 25%, 50%, and 75% in volume. The total dry biomass obtained is 2.49, 2.88, and 5.40 g, respectively. The average growth is, respectively, 0.75, 1.14, and 3.66 g. The best increase is obtained with a ratio of 75% of compost additive which is not confirmed at the root part. It is the same case for the height of the shoot part, which presents an average growth of 0.65, 2.45, and 4.20 cm. Also, in this case it is worth mentioning that the best response is obtained for a ratio of 25% as shown in Figure 4.

The efficiency of compost amendment in the soil is confirmed as soon as the period of composting is between 120 and 150 days. The evaluation of the impact of incorporation of compost at different ratios (25%, 50%, and 75%) in volume has confirmed a noticeable improvement

Table 5. Physicochemical properties of the used soil.

Particle size (%)		Organic matter		Exchangeable bases (meq/100 g)	
Fine soil	0	Organic matter %	0.7	Ca	6.3
Clay	6.8	Organic carbon %	1.41	Mg	0.2
Fine silt	9.7	Total nitrogen %	0.5	Na	0.3
Coarse silt	0.8	Total phosphorus (‰)	2.39	K	0.15
Sandy	50.6	Phosphorus (‰)	0.048	Cation exchange capacity	7
Coarse sand	34.5			pH	7.53
Total limestone	0.8			Salinity	0.1

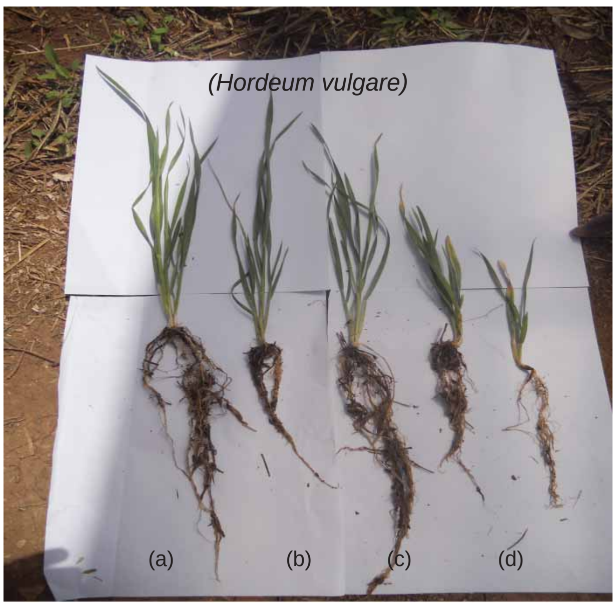

Figure 5. Comparison of the development of shoots and roots of *H. vulgare*. With different compost concentrations: (A) 75%, (B) 50%, (C) 25%, and (D) soil check sample.

on both the biomass and the height of the tested plants. These results had also been observed with other types of compost.[61,62] El Hanafi Sebti [63] had shown that the addition of compost made from tea waste had a positive effect on tomato productivity: the vegetal biomass, the number of fruits, and the weight of the roots increased with respect to the check samples. Moreover, [64] have studied the growth of *Lactuca sativa* in the presence of a compost at different concentrations. In the best case, they have obtained a growth of the plant 2–3 times greater with the presence of compost, compared to that of the check samples after 6 weeks of experiment.

The obtained results are illustrated in Figures 3 and 4 allowing the underlining of the best efficiency of the biomass of the shoot and root parts of the plant with the addition of 75% of the compost. However, for the root part, the best result is obtained with a compost incorporation ratio of 25%. This latter result seems more interesting since it does not alter the composition of the soil (hardness, permeability, and structure). In this field physicochemical analyses have to be carried out for soils with different ratios in order to evaluate the optimal quantity of compost to be added for the preservation of the agronomic characteristics of the soils (texture, structural stability, ease of work, and fertility).

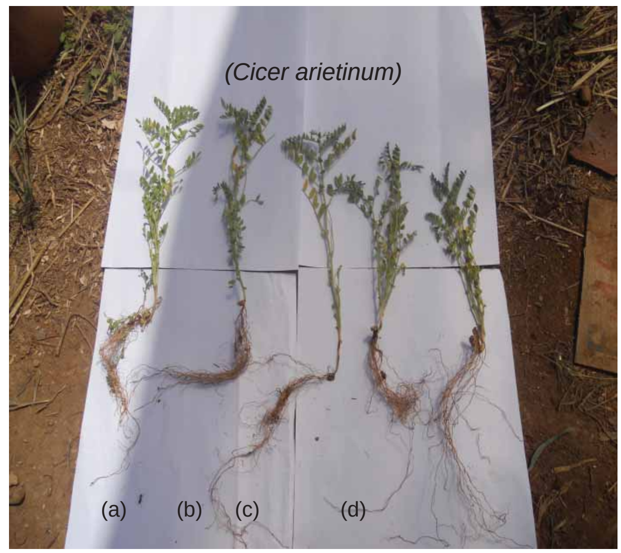

Figure 6. Comparison of the development of shoots and roots of *C. arietinum*. With different compost concentrations: (A) 75%, (B) 50%, (C) 25%, and (D) soil check sample.

Figures 5 and 6 show the comparison of the development of shoots and roots of the two plants (*H. vulgare* and *C. arietinum*) with different compost concentrations, respectively (75%, 50%, and 25%), in volume with respect to soil check sample. Compost application to an agricultural field remains an excellent and environmentally friendly approach. Recent compost research show the increasing interest in compost utilization and its benefits in agricultural plant and soil performance.[65–67]

4. Conclusion

The study concludes that throughout the 150 days of sewage sludge and green waste composting, physicochemical analysis shows that all parameters reached relatively stable levels, reflecting the stability and maturity of the final product, and revealed the biodegradation of components that can be easily assimilated by microorganisms. The C/N ratio of 15.4 reaches its optimal value of a stable compost; inorganic nitrogen is transformed into stable organic forms. The compost can supply all micro- and macronutrients necessary for plant growth. The total concentrations of Zn, Cu, Pb, Ni, and Cd are very low, rendering the final compost acceptable for agricultural use.

The monitoring of heavy metal characterization during composting shows that mobility and bioavailability of heavy metals are dependent on other physicochemical properties of the medium, besides total metal contents such as decomposition of organic matter, HS content, and pH. The composting process significantly produced a stable and mature compost and an average germination index of 93% for *H. vulgare* and *C. arietinum*, significantly encouraging the utilization of the compost.

Disclosure statement

No potential conflict of interest was reported by the authors.

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