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Recovery of sludge from the sewage treatment plant in the city of Fez (STEP) through the composting process

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Abstract

Biological wastewater treatment involves the production of large quantities of sludge. The latter present a source of pollution for the environment hence the need for their valorisation. This work proposes their valorisation by co-composting with other substrates rich in carbon and nitrogen. The substrates used are organic household waste, poultry droppings and margins. Two types of composts were developed, one with sludge and the other one without sludge, which served as a control. Indeed, the characterization of the sludge taken from the wastewater treatment plant of the Fez city after digestion and cogeneration of other substrates shows that the sludge is black in colour, had a neutral pH, and carry a very high mineral and organic biodegradable charge and these substrates are heavily loaded with chrome. Their composition in other metals (Cu, Pb, Zn, Co, Ni, and Cd) respects the limit values recommended by the French standards. Household waste is rich in organic carbon and nitrogen. Poultry droppings are weakly basic and have average levels of nitrogen, organic carbon and organic matter. The margins are moderately acidic and rich in organic matter. The monitoring of the evolution of the composting process took place by measuring the physicochemical parameters up to the maturation phase obtained after 16 weeks for both types of compost. Maturation tests for both composts were carried out on the germination of watercress and corn by measuring the E4 / E6 ratio. The mature composts thus produced reach the standards quality of a mud and urban compost, respectively NFU 44-095 and NFU 44-051, and do not present any risk of toxicity.

1. Introduction

Today, Morocco has 80 biological wastewater treatment plants in operation. Every wastewater treatment plants generates significant quantities of sludge, estimated at 40 000 T / year in 2010 and projected to rise to 300 000 T / year for the year 2025 [1]. The sewage treatment plant in the city of Fes alone produces 120 t / day, is about 43,800 t / year [2].

The sludge from sewage treatment systems is rich in organic matter, nitrogen, phosphorus and trace elements [3], and is recognized by their fertilizing power. Nevertheless, the sludge of the wastewater treatment plants (STEP) may also contain trace metallic elements (Cr, Zn, Cd, Hg, Pb ...) [4.5]; Organic pollutants (phthalates, PCBs, PAHs ...) [4] which are likely to cause adverse effects on receiving media, and emerging pollutants [6] which are classified as more than 30 000 chemicals produced in excess of standards [7]. These different sources of pollutants are the origin of the genotoxic and cytotoxic power of sludge [8]. To this, it is added the richness of STEP sludge in pathogenic germs and parasites, namely protozoa such as ***Amoeba***, ***Toxoplasmagondii***, ***Giardia***

lamblia and ***Cryptosporidiumsp***., As well as helminths such as ***Ascaris sp***., ***Trichuris sp***., ***Capillaria sp***., ***Schistosoma sp***., And ***Taenia sp***., [1] hence the need to choose the path of their valorisation.

The most commonly used sludge treatment or disposal processes is the stabilization (dehydration, liming), incineration; which remain excessive for the Moroccan context; Direct landfill, landfill disposal [9]. But this sector is legally banned in many countries. Other methods are less well known or Still the study, like the incorporation of sludge in the manufacture of cements and concretes [10-13], packaging (bioplastic), regeneration of degraded sites, the production of biological insecticides, and bio-fungicides and herbicides.

At present, no sludge treatment system is used in Morocco. Nevertheless, several studies have proven effective results when using sludge in agricultural spreading [14], composting in a mini-reactor [15], the composting process and the metallic transformation and the organic pollutants [16-18].

The aim of this study is to evaluate the mud generated by the wastewater treatment plant in the city of Fez in the composting process. For this purpose, we developed two types of composts: the first with sludge and the second one without sludgewho served us as a witness.

2. Materials and methods

2.1. Materials

The waste used for composting is composed by: mud, household and green waste, poultry droppings and margins.

- The mud was removed from the Wastewater Treatment Plant.
- Poultry droppings were purchased from some farms in the Ain Chgag region of Fez.
- The margins have been proposed as storage basins made by the Autonomous Water and Electricity Distribution Authority of Fez (AWEDAF) (RADEEF).
- Household and green waste was provided from the Bensouda wholesale market and sorted.

All materials were characterized by temperature, conductivity (EC), moisture content (% H), organic matter (% MO), Kjeldahl nitrogen (NTK) and C/N ratio. The same parameters were used to composting process.

2.2. Sampling

Samples of different substrates, mixtures and mature composts were taken by the composite method, taking 2 kg of different locations and depths that are then mixed and homogenized according to the quenching method. Then, a representative sample of 1Kg was taken and put in plastic bags numbered and stored at -20 ° C until it was analysed [1].

2.3. Methods

❖ Compost elaboration

Two types of mixing of the substrates, with a grain size of less than 100 mm and a quantity of 70 tonnes each, were produced in the form of swaths; One with mud (CB) and the other without sludge (C) which played the role of witness. The composition of each one was determined from the moisture of the substrates and their carbon and nitrogen contents. The two swaths were moistened by adding a calculated amount of margins dependent on the new composition of the mixture at time to ensure the survival of the microorganisms and the transport of the particles, contact between the organic fractions and the microbial flora [21].

❖ Maturation tests

The maturation tests for composts C and CB were carried out by determining the E4/E6 ratio and by calculating the plant test and the germination index (IG). The E4/E6 ratio was performed by the spectroscopy method that uses the property of a body which absorbs light at different frequencies. The ratio of the light absorption of a humic acid solution at different frequencies of 465 and 665 nm is the E4 / E6 ratio [22].

The plant test was carried out on watercress with compost in trays. Ten watercress seeds, LepidiumSativum L, were spread on the surface and covered with a glass plate. A daily follow up to the fifth day was carried out all the time of germination and then the germinated seeds were cutted and weighed [23].

The germination test was carried out on maize seeds, Zea mays variety and watercress, LepidiumSativum L variety, with an aqueous extract of compost (compost juice) in petri dishes with filter paper [24]. Ten corn seeds and ten watercress seeds were distributed on the filter paper and incubated at room temperature (28 ° C) in the dark for 48 h [39]. The number of germinated seeds was counted and root lengths were measured. One control for each treatment was made with 10 mL of distilled water. The parameter GI was calculated using the Zucconi formula [40].

- Quality of mud and composts

The quality of the sludge from STEP and the composts was evaluated by the analysis of some heavy metals likely to be present (copper, chromium, lead, zinc, etc.). The concentrations of the heavy metals were determined by inductively coupled mass spectroscopy (ICP) after the mineralization of the samples in question with nitric acid (HNO_3).

3. Results and discussions

3.1. Characterization of the initial substrates

The physicochemical characterization of the initial substrates is listed in Tables 1 and 2. The analysis of the results of Table 1 shows that the sludge from the STEP of the city of Fez is almost neutral, rich in organic matter and nitrogen, and characterized by a C / N ratio of 21.13.

Poultry droppings are weakly basic and have average levels of nitrogen, organic carbon and organic matter of 1.05%, 15.11% and 26.05%, respectively.

The margins are slightly acid, rich in organic matter but low in nitrogen, making a C / N ratio of 50.28. Organic and green household waste is rich in nitrogen and organic matter with a C / N ratio of 24.7.

Table 1: Physico-chemical characterization of the substrates

Paramètres	Boue	Déchets ménagers	Fientes de volailles	Margine
pH	6,63 ±0,11	6,1 ±0,08	8,2 ±0,04	4,91 ±0,04
CE (mS.Cm-1)	4,81 ±0,02	1,65 ±0,05	8,02 ±0,08	7,76 ±0,4
H %	71,55 ±1,05	51,47 ±1,36	73,71 ±1,04	88,13±0,69
MO %	51,37 ±0,01	76,78 ±0,25	26,05±0,07	77,87 ±1 ,01
COT %	29,8 ±0,04	44,54 ±0,06	15,11 ±0,08	7,04±0,03
NTK %	1,41 ±0,01	1,85 ±0,04	1,05 ±0,01	0,14±0,01
C/N	**21,13±0,13**	**24,1 ±0,8**	**14,39 ±0,14**	**50,28±3,93**

The metallic characterization of the sludge (Table 2) shows that their heavy metals charge is in compliance with the French standard for sludge admitted to composting, NFU STANDARD NFU 44-095, with the exception of the chromium element (Table 2). Indeed; the latter is supplied by wastewater of different origins, domestic, urban and industrial (dinandies, tannery, pottery) neighbouring the wastewater treatment plant.

Table 2: Composition of the sludge in heavy metals

Content of MTEs in (mg / kg)	Cu	**Cr**	Pb	Zn	Co	Ni	Cd
Sludge	210	**22992.5**	155.275	31.5	7.525	76.5	00
Permissible limits in composting sludge (NFU 44-095)	1000	**1000**	800	3000	14.625	200	10

Table 3 shows the physicochemical characterization of the initial mixtures at t = 0. The results of their characterization indicate that they are moderately basic with a pH of 8.09 for the mixture C and 8.66 for the mixture CB. The mixture C is richer in nitrogen and in organic matter with a C / N equal to 29.4 and greater than that of the CB which has a C / N equal to 28.97.

Table 3: Physico-chemical characterization of the initial mixtures

Parameters / Composts	pH	CE (mS.Cm^{-1})	MO %	COT %	NTK %	C/N
CB	8,60±0,1	2,26±0,05	74,425±0,25	43,170±0,06	1,49±0,04	28,97±0,14
C	8,09±0,01	2,85±0,06	78,125±0,28	45,316±0,07	1,54±0,04	29,4±0,17

3.2. Monitoring the composting process

3.2.1.Monitoring the temperature

The first index that reflects the degree of degradability of the compost is temperature. In our case, the curves representing the evolution of the temperature as a function of time for the two composts (Figure1) have a classical appearance of composting, characterized by three important phases: mesophilic, thermophilic and maturation.

- The mesophilic phase is the initial phase of composting where the raw materials is invaded by mesophilic microorganisms (bacteria and fungi), absorbing simple molecules (simple sugars, amino acids, alcohols ...) and transforming some of the polymers Proteins, nucleic acids, starch, pectin, hemicellulose, cellulose, etc.). Their activity has engendered a rise in temperature of 30 ° C to 40 ° C for the C pile and 33 ° C to 45 ° C for the CB pile. This difference is due to the difference in the development period of the two composts. The mesophilic phase lasted almost four weeks for both composts.
- The thermophilic phase is characterized by an increase in temperature up to 75 ° C. and 73 ° C for CB and C respectively and lasted for about 5 weeks for C and 7 weeks for CB. Indeed, the increase in temperature is the result, on one hand, of an intense microbial activity which results from the degradation of the simple molecules present in the substrates [22-25]; And on the other hand, the inertia of the compost mass, which gives it a self-insulating capacity and maintains a high temperature inside the windrow.
- The maturation phase is distinguished by a decrease of temperature to the ambient in the two windrows where the microbial flora is dominated by the mesophilic organisms. The decrease in temperature is due to the depletion of the medium in easily metabolizable organic compounds; and persistence of compounds resistant to degradation (lignin, cellulose ...) [15]. It is dominated by humification reactions which consist in the polymerization of organic compounds towards more stable compounds called "Humus" [26]. The composting period C is 7 weeks compared to 5 weeks for CB compost. The maturation of control compost C began at the 9th week and lasted 6 weeks. While CB sludge compost started only at the 11th week and lasted only after 5 weeks. So, the presence of sludge in composting extended the thermophilic phase by 2 weeks and accelerated the maturation period by reducing it to 5 weeks instead of 7 weeks compared to the control compost.

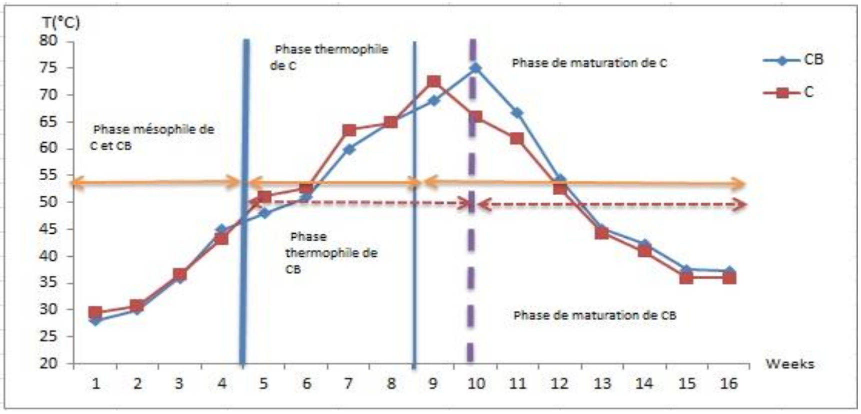

Figure 1: Evolution of the temperature of composts C and CB

3.2.2.Monitoring of pH

Or the pH evolution (Figure2), there is a slight decrease in the mesophilic phase. This decrease is due to the production of organic acids and to the dissolution of organic carbon in the medium where degradation of simple carbohydrate and lipid molecules [27; 28]. After four weeks, the pH increases and marks the beginning of the thermophilic phase of the composting process. This is due to the ammonification and the ammonia production from the degradation of amines (proteins, nitrogenous bases, etc.) [29], and may be due also to release of existing bases in organic waste [30, 31]. At the 9th week, the pH of the compost C decreased slightly, while for the compost CB, the decrease is only reached at the 11th week. Then, they stabilize from the 11th week for the control compost and at 13th week for the sludge compost. This means that the sludge slows the function of the thermophilic microorganisms for the degradation of the amines. Finally, the stabilization of the pH around 8 for the both composts proves the buffering capacity of the humus during maturation. Moreover, for this phase the pH remains stable, with an optimum value between 6 and 8 [17, 32].

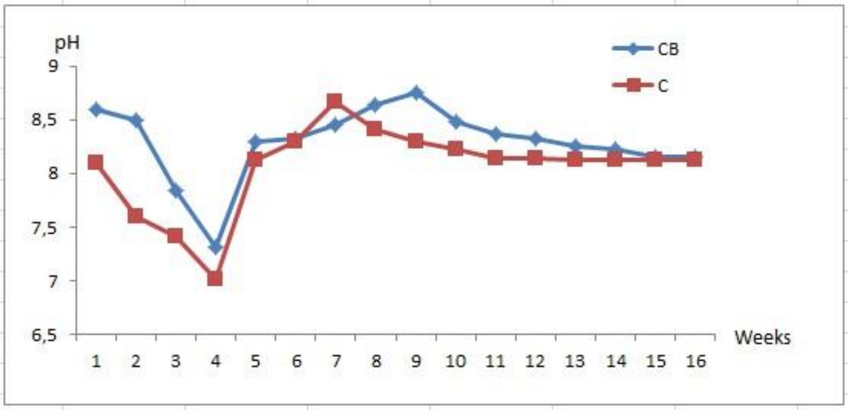

Figure 2: Evolution of the pH of Composts C and CB

3.2.3.Monitoring the Conductivity

The electrical conductivity of the both composts C and CB increases from the first weeks; showing the mineralization of organic matter (Figure 3). In the maturation phase, the conductivity of the compost C tends to decrease and to stabilize in the maturation phase at 2.55 mS.cm-1.

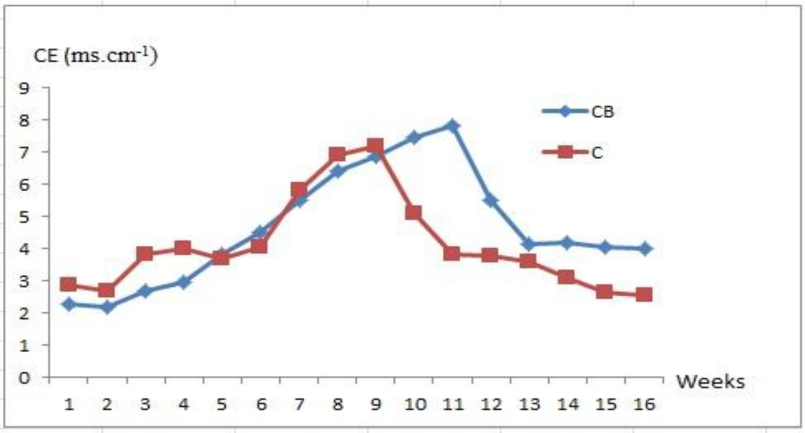

Figure 3: Evolution of the conductivity of composts C and CB

Whereas that of CB compost, stabilized at a value of 4.01 mS.cm-1 at the end of the composting process; A higher initial mix value of almost 46% and a 56% decrease for the control. This difference could be explained by the fact that the control compost is rich in fermentable elements which give off more heat per unit of mass and slightly inhibits the activity of the microorganisms due to the reduction of the gap in the compost. Although the conductivity values obtained at the end of the process can be explained by the theory of Avnimelech et al. Who say that a reduction in conductivity of 8 mS.cm-1 to 4 mS.cm-1 starting from a conductivity waste of 2.5 mS.cm-1 is due to the good aeration of the compost; which has affected the concentration of salts and the conductivity [33].

3.2.4.Follow-up of the organic matter of composts C and CB

It is noted that the results from the evolution of the organic matter of the two composts as a function of time corroborate those obtained for the evolution of the pH (Figure4). Indeed, the organic matter content decreases for both composts. For both composts, which means good degradation of the latter until reach stability towards 40% and 50% respectively for the 2 composts C and CB. This could be probably due to the fact that microorganisms, by the action of the enzymes, they produce and decompose organic matter into simple elements, called nutrients, that will use for their own needs and functioning (reproduction, Growth, ...) [34].

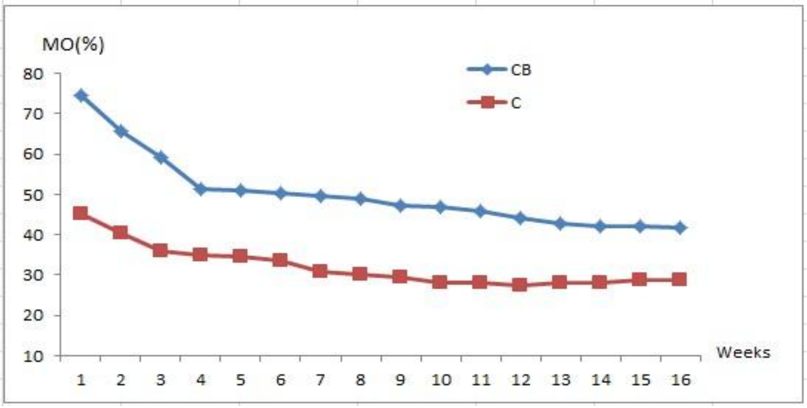

Figure 4: Evolution of the organic matter of compost C and CB

3.2.5.Follow-up of the C/N ratio of the composts C and CB

The C/N ratio increases from 28.97 and 29.42 to 12.38 and 13.03 for the composts C and CB respectively at the end of the co-composting (Figure 5). The reduction of this ratio is closely linked to the loss of organic carbon by biodegradation of organic matter and the evolution of CO2 gas; and on the other hand, and it is to increase in the total nitrogen content of the medium which increases from 1.49 to 1.952 for the compost CB and from 1.54 to 2.22 for the compost C.

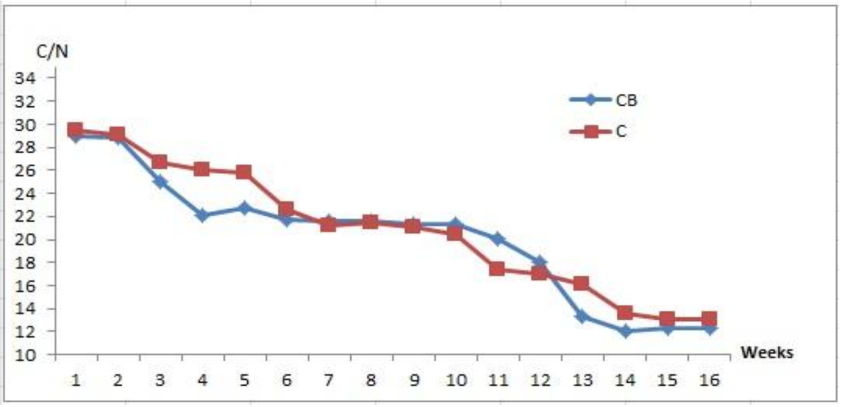

Figure 5: Evolution of the C/N ratio of composts C and CB

The decrease in this ratio is attenuated by the loss of nitrogen in ammoniacal form during the thermophilic phase [17, 35] and by leaching during the moistening by margins. The final values reached with C/N, close to 15 after 4 months of co-composting, show a good maturity of the final compost. Indeed, according too many authors [36; 37], a compost is considered mature if it has a C/N ratio between 10 and 15. These variations depend mainly on the nature of the nitrogen molecules and their ability to be mineralized and on the other hand, on the nature of the compounds Carbonates present in the substrate to be composted [38].

3.2.6.Qualitative and quantitative monitoring of composts

During composting, both the total volume and the mass for both composts were reduced. This decrease has two main relative factors:

- The decrease of volume by settlement over time.
- The fragmentation of the substrate due to the progressive destruction of the total mass of the particles at constant humidity by reduction of the mass and of the organic matter due to degradations accompanied by losses of carbon and by the departure of the carbon dioxide and the volatile compounds in parallel. The rise in temperature leads to losses of water by evaporation.

3.3. Maturation tests for composts C and CB

3.3.1.Test E4 / E6

The ratio E4 / E6 is 3.2 and 2.9 for the compost CB and C respectively. Both values are less than 5, indicating the presence of humic acid. So an advanced stage of decomposition is reached. Indeed, the low ratio explains that the composts are ripe and the humus particles are large and complex and are not the particles of the organic matter. The composts lead to reduce their particle size and to increase this ratio [22].

3.3.2.Test Plant

The results of the plant test reveal that the weight of the germinated seeds is 84.62 g for the compost CB and 73.7 g for the compost C. These weights are between 60 and 100 g, which prove the absence of toxicity in the composts. An advanced thrust of cress seeds and a good quality of elaborate composts is reached[20].

3.3.3.Germination Index (GI)

The analysis of the germination index results shown in Table 4 indicates that the mean values of five replicates are an indicator of maturity and the stability of the compost (GI> 50%) [41].

Table 4: mean value of germination index

Germination Index (GI)	Variety tested	Compost with mud	Compost without mud
	Corn	84 ,56	78,34
	Cress	88,65	80,2

3.4. Evaluation of the quality of composts C and CB

The evaluation of the quality of composts C and CB was carried out by the analysis of the physicochemical and metallic parameters after maturation (Tables 5 and 6); Obtained after 4 months of follow-up. The mature composts C and CB are moderately basic with a pH of 8.13 and 8.15 respectively, and are rich in nitrogen and organic matter. The C / N ratios of the two composts are in the maturity standards of good compost [41].

Table 5: Physico-chemical characterization of the composts C and CB.

	pH	**CE ($mS.cm^1$)**	**MO %**	**COT %**	**NTK %**	**C/N**
Compost with mud	8,15±0,01	4,03±0,04	41,66±0,01	24,17±0,02	1,95±0,1	12,38±0,1
Compost without mud	8,13±0,01	2,55±0,06	49,85±0,13	28,91±0,01	2,22±0,09	13,02±0,14

Table 6: Composition of heavy and heavy metals CB and C

Content of ETM in (mg/kg)	Cu	Cr	Pb	Zn	Ni	Cd
Compost CB	22.5	116	104	227.2	51.5	00
Standard of a sludge compost (NFU 44-095)	300	120	180	600	60	3
Compost C	13	6,5	13,5	105	11,6	0,1
Standard of an urban compost (NFU 44-051)	100	12	100	300	50	8
Limit values class A (no risk in use) mg / kg dry peas	100	----------	150	500	62	3

The Comparison between the composition of composts C and CB with French standards reveals that the content of most metals has decreased compared to that of sludge (Table 2), with the exception of Zinc, which has increased while remaining within the standards quality of NFU 44-095 sludge compost and the French NFU 44-051 standard [42]. For the other metals, the concentration increased from 155.2 mg / kg to 20.55 mg / kg for Pb, from 210 mg / kg to 22.5 mg / kg for Cu, from 76.5 mg / kg to 51.5 mg / kg for Ni. This decrease may be the result of the leaching of these metals by the water produced during the degradation of the organic matter and by leaching during the humidification of the windrows. On the other hand, some changes in physicochemical characteristics such as pH and electrical conductivity influence the solubilisation or the transformation of these elements [43]. It can be deduced that the decrease in the total rate of heavy metals is strongly related to a decomposition of the organic matter during the thermophilic phase and that these latter precipitate and become immobile in the presence of the carbonates. In general, heavy metals are immobilized by organic matter and the phenomenon of adsorption of the organic matrix which can contribute to the decrease of their concentration [42].

In the light of these data, the total contents of the heavy metals (Pb, Cd, Cr ...) in the final compost is lower than that in activated sludge alone. After 4 months of co-composting, the products obtained meet the standards of use (AFNOR, 1993) to the NFU 44-095 standard for sludge composts of the STEP and the French standard of urban compost NFU 44-051. As a result, the composts thus produced can be classified in category A of the composts [42] and can be used in agriculture as an amendment for soils without risk of contamination of the soil-plant system.

Conclusion

The digested and congealed sludge of the FES STEP estimated at 120 t / d is characterized by their richness in organic matter and nitrogen, a C/N ratio of 21.13 according to the sludge standard accepted for composting (NFU 44-095). This proves their valorisation in the composting process with other substrates (household and green waste, poultry droppings and margins). Two mixtures of different substrates and compositions were made; One with CB sludge and the other without sludge C constituting the control.

The mixtures of the initial substrates at t = 0 for the production of composts C and CB are slightly basic, rich in carbon, in nitrogen and organic matter and are characterized respectively by C/N ratios of 29.4 and 28.97 belonging to the validation interval of the waste for the composting.

The monitoring of the composting process was carried out by weekly measurements of temperature, pH, conductivity, organic matter, carbon and nitrogen for 4 months. The mesophilic phase of the two composts C and CB was obtained after 4 weeks. The thermophilic phase is the longest phase; it was 5 weeks for the control compost C and 7 weeks for CB compost. Stabilization of the various parameters of compost C and CB took place after the 9th and 11th week respectively and 5 weeks for compost C and 7 weeks for CB compost. The presence of the mud in the compost slowed down the thermophilic phase and accelerated the maturation phase.

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