Conception And Comparative Analysis Of Different Biocomposts

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Abstract: The Rabat Botanical Testing Garden produces a quantity of 5 tons per week of green waste, which is collected and then evacuated to landfills. As a result, there is an obvious need for recovery through composting, in order to include the site in a circular economy approach. This work aims to recover green waste from the Rabat Botanical Test Garden, and those through the design and construction of a composting platform, and on the other hand the use of the final compost as an amendment. fertilizer to all the plants in the garden. This article proposes to study the physical-chemical and bacteriological parameters of three composts of different natures. The results showed that from a physicochemical point of view there is not a big difference between them in terms of organic matter and nutrient content. On the other hand, from a bacteriological point of view, the results show the absence of pathogens such as Salmonella-Shigella SSA at the level of the three composts. As a result, we see that despite the difference in origin of the composts, the nutrient contents remain similar, thus making it possible to achieve the best composition based only on the green waste from the Garden to develop a compost that is mature and ready for the use as an organic amendment, without resorting to the contribution of other materials outside the Garden.

Keywords: Green waste, Composting, Organic Matter, Microbiology, Circular Economy, Fertility.

1 INTRODUCTION

The society is distinguished by the increase in demand for consumable products, which indicates the greater development of reproductive technologies, and consequently an increased production of waste of various kinds.

Landfilling is widely used for the treatment of municipal solid waste and green waste (Reyes-Torres et al. 2012), thus affecting human health, the environment and also the quality of life in society as a whole.

Solid waste management is a huge challenge in developing countries, due to population growth, poverty and lack of adequate investment from governments. As a result, the lack of infrastructure for the proper treatment of solid waste and the indiscriminate disposal of waste leads to the accumulation of waste in large quantities (Campan 2010), which by its nature constitutes a serious threat to the health of human being and the environment (Lim et al., 2016).

In Morocco, the total waste generated is 5.3 million tons per year, with a forecast of reaching a deposit of 39 million tons by 2030. The implementation of recovery and recycling processes should allow contribute to reducing the cost of environmental degradation linked to waste management, the cost of which has been assessed at 3.7 billion dirhams or 0.4% of GDP.

There are many types of solid waste produced from the city, some of them are recyclable, but the largest amount is organic material. For the Moroccan context, domestic solid waste is composed of: plastic (38%), paper (41%), metals (14%) and glass (5.5%) (Minister Delegate to the Minister of Energy, Water and the Environment Environmental Charge Morocco). These wastes have a considerable role in the pollution of the environment if they are not treated correctly. Besides landfilling, incineration and pyrolysis, the biogas process and composting are used to dispose of organic waste. The advantages of the latter two processes are that they reduce environmental damage and produce economically valuable products.

The composting of organic waste reproduces the natural process of transformation in the soil of fresh organic matter, of animal and plant origin, into humified organic matter, commonly called humus. It is an ancient practice, evidence of which can be found in distant Roman and even Egyptian civilizations (Martin, 2000).

Intensive agriculture or phenomena such as erosion lead to the reduction in the organic matter content of the soil, causing a drop in its fertility. The use of compost in agriculture could make it possible to combat this trend of soil degradation. Indeed, it is generally accepted that composts contribute to the maintenance of organic matter in soils, thus improving their physical, chemical and biological properties, and that they provide fertilizing elements to crops (Leclerc, 2001).

The site under study is the Botanical Garden of Rabat in Morocco, which is characterized like all green spaces by a high production of green waste, which generates both an economic and environmental challenge relating to the management of this waste and its disposal.

This present work aims to include the study site in a circular economy approach, aiming on the one hand at the recovery of green waste from the Botanical Test Garden of Rabat, and those through the design and creation of a composting platform, and on the other hand the use of the final compost as a fertilizer amendment for all the plants in the garden.

To do this, the study proposes to study three composts of different compositions, by carrying out a comparative analysis between them, in order to choose the best composition and to develop a typology of compost rich in nutrients which is based only on the garden waste.

2 MATERIALS AND METHODS

2.1 The study site

The The Botanical Test Garden of Rabat exists in the city of Rabat, which is located on the Atlantic coast in northwestern Morocco, 40 km south of Kenitra and 87 km north-east of Casablanca, it is separated from the town of Salé at the mouth of the Bouregreg. It covers an area of 118.5 km2.

Created in 1914 on a total area of 17 ha, the botanical test garden of Rabat is an experimental domain of INRA responding to many missions including: conservation, research and environmental education.

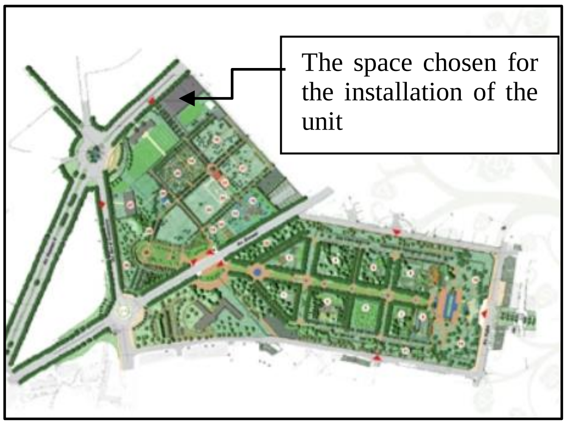

Figure 1: The Botanical Test Garden of Rabat

The choice of site is justified by logistical and environmental reasons, in particular:

- The absence of risk of transfer of pollutants to surface water and groundwater, the site is far from surface water and drinking water catchments by a distance of more than 500 m.
- The absence of risk of dissemination of a microbial mass or contaminants in the air through dust and spores.
- Proximity to the site of the waste production area.
- The possibility of extending the site.
- The site is close to drinking water catchments.

Figure 2: The experimental site

2.2 Presentation of the experimental pilot

Facilities at the experimental pilot should be close together to minimize travel. For this reason, our unit consists of several spaces dedicated particularly to the different stages of composting, in particular:

- Reception area
- Fermentation area
- Ripening area
- Packaging and storage area

2.2.1 Windrow design

In composting, there are several methods to produce mature compost. The choice of technique depends on several factors including technical, ecological and legislative. In our study, the choice of technique was based on the following points:

- The climatic and socio-economic context of most of our regions as well as the availability of land in agricultural areas, it is recommended to opt for a semi-mechanized technology of the "windrow" type (soudi, 2005). This process is technically acceptable and economically viable for the case of organic waste.
- From a time point of view, windrow composting increases the speed of the process, which leads to minimizing the duration of composting.
- Working on a small surface. Considering that the space available for the installation of the unit is a little restricted.
- Controlling odor management through good heap oxygenation and normal CO2 evacuation.

Thus, the composting process studied is windrow composting. The study is carried out on 3 composting windrows with two main objectives that link the environment and agriculture: to eliminate the green waste produced by the garden in large quantities and to valorize it by producing compost that has an economic value.

Consequently, the windrows are made from crushed green waste to facilitate their biodegradability and therefore their composting, and straw which provides a supply of carbon easily available to micro-organisms as well as good aeration of the windrows by maintaining the porosity of the pile.

The windrows are moistened from time to time to maintain an optimal humidity percentage for composting, which is between 50% and 70% (Marai chapter 12).

Regarding the dimensions of the site, the plot covers an area of 150 m2, the width of each windrow is 1.80 m while the length is 2.50 m (Figure 3).

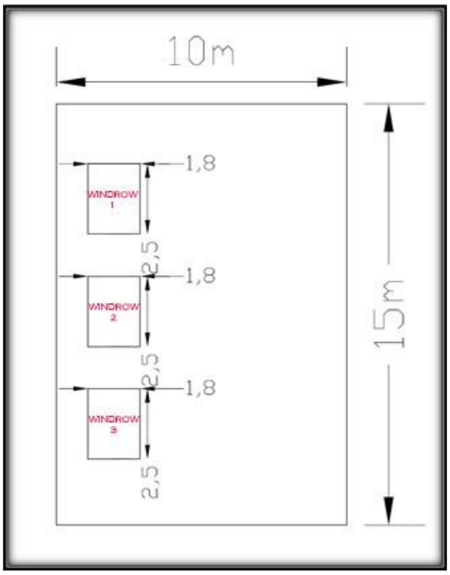

Figure 3: synoptic diagram of the experimental pilot

2.2.2 Windrow A1

Mixture of green waste with straw and sheep manure.

2.2.3 Windrow A2

Mix green waste with straw only.

2.2.4 Windrow A3

Mix of green waste with straw and organic household waste.

2.3 Materials

At the level of this study, a variety of materials was used, whether for preparation, characterization and sampling.

2.3.1 Crusher

The shredder is used to reduce the size of branches and refine dead leaves for rapid decomposition.

Product features:

- 60 mm rotor shredder with reversible hammers.
- Grinding diameter 1.3 cm.
- Production from 9 to 11 m3/h

2.3.2 Temperature probe

This compost thermometer allows to:

- Measure the temperature at the heart of the compost heap.
- At a minimum, a monitoring every three days of the temperature is carried out for each batch during the fermentation phase.

Product Features:

- Length: 40cm
- Dial diameter: 4 cm
- Material: Stainless steel

Figure 4: Temperature measurement with the probe thermometer

2.3.3 Aerator

The aerator consists of a long rod at the end of which are two fins. Once pushed into the pile, the aerator fins will open when pulled up. It is enough to dip the aerator several times in different places of the pile. The aerator thus immersed in the pile allows the circulation of air and facilitates the transport of decomposing organisms (natural accelerant) to the surface. The ventilation thus achieved avoids frequent turning and helps to keep the internal heat of the pile.

Figure 5: aerator

2.3.4 Colony counter

The colony counter is suitable for reliable and efficient counting:

- Colonies of bacteria on Petri dishes
- Phage plates developed on agar
- Colonies of bacteria developed on nutrient discs

Usable with a pen tip, the pressure exerted on the Petri dish triggers the counting and performs the incrementation from 0 to 9999.

Figure 6: Colony counter

2.3.5 Green waste used

The solid waste used consists mainly of residues from the Garden nursery, in particular:

- Type 1: wood
- Type 2: palm leaves
- Type 3: leaves of old trees
- Type 4: leaves of young trees
- Type 5: flowers and leaves of Rosaceae
- Type 6: grass

2.3.6 Other waste used

To complete the combinations, we used other types of waste including:

- Sheep manure
- Organic household waste composed of: vegetable and fruit remain
- Straw

2.4 Sampling

The sampling method adopted in the context of our experimental pilot is "composite sampling".

A composite sample is produced by mixing a series of grab samples taken in accordance with a pre-established sampling strategy (Walloon Compendium of Sampling and Analysis Methods (Cwea)).

For our case study, we take ten (10) samples from different points and depths (10cm and 30cm), then mix them to form a so-called composite sample (representative sample).

The sampling frequency is once every 10 days, from the beginning until the end of the composting process.

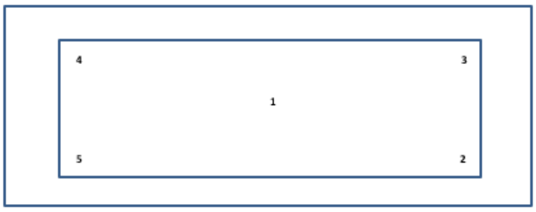

Figure 7: Diagram of sample collection points

2.5 Physico-chemical and microbiological characterization of the compost

2.5.1 Physico-chemical characterization of the compost

To guarantee a good start to composting, three essential parameters must be controlled: the C/N ratio, the humidity of the mixture and the size of the particles.

For our study, we opted for the monitoring of the following parameters:

- pH: the pH in the water and the pH in KCL are measured using a pH meter after 16 hours of rest.
- Conductivity: The method consists of extracting the sample with water, to dissolve the electrolytes, then measuring with the conductivity meter after 16 hours of rest.
- Organic matter: determined by the WALKLEY & BLACK method, whose oxidation is incomplete and cold.
- Assimilable phosphorus: The determination is carried out by colorimetry using the ceruleomolybdic method of DUVAL, which is based on the formation and reduction of a complex of orthophosphoric acid and molybdic acid

• Total nitrogen: The determination by the KHJELDAHL method is done by carrying out the mineralization of the organic nitrogen of the soil in the form of ammonium sulphate in the presence of concentrated sulfuric acid. By treatment with steam, ammonia is released in an alkaline medium and the dosage is carried out by acidimetry.

• Sodium and potassium: extraction using ammonium acetate CH3COONH4 then the concentration of the sample in K^+ and Na^+ is measured in ppm (parts per million) using a flame spectrophotometer, and directly from the solution extraction.

• Temperature: on-site measurement using a probe thermometer.

2.5.2 Microbiological characterization of the compost

The monitoring of microbial populations is carried out by the method of counting viable germs on culture medium on Petri dishes, it is a direct, rapid, reproducible and less expensive evaluation technique.

The count concerned: Total aerobic mesophilic flora (FMAT), total coliforms (CT), faecal coliforms (CF), fungi and molds, Staphylococcus aureus, Salmonella-Shigella.

The microbiological analyzes are carried out using a suspension of 1 g of compost from each sample, in 9 ml of sterile physiological water.

The suspension is then well agitated in order to release the maximum of the microbial load. Then, serial dilutions up to 10^{-9} are performed.

After having prepared the culture medium corresponding to each type of microorganism sought, and the necessary dilution series, we proceeded with the inoculation.

Each inoculum is seeded on the surface or in depth depending on the culture medium used.

The various manipulations are carried out in the sterile zone of a flame (Bunsen burner) to avoid any contamination.

All the dishes corresponding to each dilution are incubated in the oven at different temperatures and times as indicated in the following table:

Table 1: the temperature and incubation times of the culture medium

Microorganisms	T (°C)	Time (h)
FMAT	30°C	24h to 48h
FMAT	44°C	24h to 48h
Staphylococcus aureus	37°C	72h
Total coliforms	37°C	72h
Faecal coliforms	44°C	72h
Salmonella-Shigella	37°C	72h
Yeasts and molds	25°C	72h

3 RESULTS AND DISCUSSIONS

3.1 Deposit of organic matter to be composted

The annual amount of waste is the basis for delimiting the area needed to mount the composting unit.

There is a variability in the quantities collected per month, this quantity is worth 260 tonnes per year on average, that to say 5 tonnes per week, including the need for rational management of space for the establishment of the composting unit. For example: during the months of April, May and June the shredding and windrowing must be done every 15 days and for the rest of the year it can be done every month, this allows good management of the available space.

On the other hand, the variation of the quantities of waste per month informs us about the maximum quantities that we will have in each area, according to the duration that the area must pass, this allows us to adjust the surface recommended for each area.

3.2 Windrow design

3.2.1 Windrow A1

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This first windrow is made up of crushed green waste, straw and sheep manure, the latter of which is an excellent source of organic matter, nitrogen, potassium, phosphorus, calcium and magnesium (Marai chapter 12).

As with all windrows, their creations are made layer by layer from their constituents (Figures 9, 10 and 11).

SHREDDED GREEN WASTE
STRAW
SHEEP MANURE
STRAW
SHREDDED GREEN WASTE
STRAW
SHEEP MANURE
STRAW
SHREDDED GREEN WASTE
STRAW

Figure 8: The layers of the A1 windrow

3.2.2 Windrow A2

This windrow is made up of shredded green waste and straw only.

SHREDDED GREEN WASTE
STRAW
SHREDDED GREEN WASTE
STRAW
SHREDDED GREEN WASTE
STRAW
SHREDDED GREEN WASTE
STRAW
SHREDDED GREEN WASTE
STRAW

Figure 9: The layers of the A2 windrow

3.2.3 Windrow A3

This last windrow is made from shredded green waste, straw and biodegradable household waste this time. The goal is to recover this waste produced in our homes in large quantities since it is leftover vegetables, fruits, etc.

SHREDDED GREEN WASTE
STRAW
BIODEGRADABLE HOUSEHOLD WASTE
STRAW
SHREDDED GREEN WASTE
STRAW
BIODEGRADABLE HOUSEHOLD WASTE
STRAW
SHREDDED GREEN WASTE
STRAW

Figure 10: The layers of the A3 windrow

3.2.3 Windrow compositions

Each composting windrow is made up of a different composition from the other windrows in terms of nature and proportion. All windrows contain the same percentage of straw. Compost 1 and compost 3 share the same proportions of green waste, but they differ in terms of material (manure for A1 and organic waste for A3). Compost 2 represents the highest percentage of green waste (Table 2).

Table 2: Constituent of each windrow in percentage (%)

	Compost 1	Compost 2	Compost 3
Straw	15%	15%	15%
Green Waste	50%	85%	50%
Sheep Manure	35%		
Biodegradable household waste			35%

3.3 Compost characterization

3.3.1 Temperature

Temperature measurements were taken every 3 days throughout the composting period (120 days), with the electronic probe thermometer.

The temperature was taken in five different positions for each windrow, then the average of these values given by the thermometer is adopted.

The first or mesophilic phase begins with a first degradation of organic matter carried out by mesophilic microorganisms such as bacteria belonging to the families Pseudomonaceae, Erythrobacteraceae, Comamonadaceae, Enterobacteriaceae, Streptomycetaceae and Caulobacteraceae, among others, which develop between 15 C and 35 C. These micro-organisms use soluble and easily assimilated compounds such as sugars, amino acids and lipids present in the raw materials used for the manufacture of compost (Bernal et al., 2009; Insam and de Bertoldi, 2007). Microbial metabolic activity generates exothermic reactions that increase the composting temperature.

Under these conditions, the population of mesophilic microorganisms becomes less competitive and is replaced by thermophilic microorganisms (Insam and de Bertoldi, 2007). During this stage, called the thermophilic phase, the proliferation of actinobacteria (mostly belonging to the families thermoactinomycetaceae, Thermomonosporaceae and Pseudonocardiaceae) and other thermophiles occurs. These microorganisms have enzymes that degrade complex molecules such as cellulose, lignin, hemicellulose and proteins (Bernal et al., 2009; Insam and de Bertoldi, 2007). Similarly, the elimination of pathogens and seeds able to germinate occurs when the temperature increases (Insam and de Bertoldi, 2007; Neklyudov et al., 2008; Vélez-Sánchez-Verín et al., 2008; Vinnerås et al. ., 2003). Then the energy sources run out and the compost heap reaches temperatures between 15 C and 35 C leading to the second colonization of the compost by mesophiles. During this stage, called the cooling phase, the mesophilic microorganisms break down the remaining amounts of sugars, cellulose and hemicellulose. In the last phase or maturation, the precursors of humic substances are formed (Bernal et al., 2009; De Bertoldi et al., 1983; Sharma et al., 1997; Shilev et al., 2007; Zapata, 2009; Zeng et al. al., 2010).

The following curve shows the evolution of the temperature during composting.

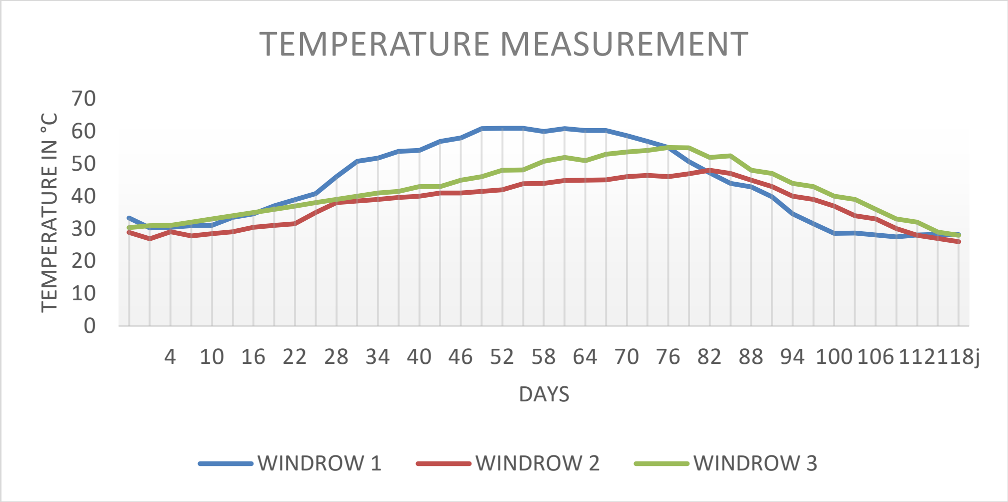

Figure 11: Evolution of temperature during composting

3.3.2 Monitoring of physico-chemical parameters of composts

Laboratory analyzes are taken directly after sampling every ten days throughout the composting process.

The following table presents the analysis results of the samples at the start of composting.

Table 3: Compost analysis results at the start of composting

WINDROW	1	2	3
MO%	82,8	73.28	80,1
C %	65,3	56,5	59,2
Ca^{2+} %	0,56	0,50	0,64
Mg^{2+} %	1,44	0,96	0,92
K^{+} %	1,33	0,91	0,83
Na^{+} %	0,46	0,34	0,35
P %	0.282	0.279	0.250
N%	3,9	1,9	2,9
pH	7,01	7,1	7,04
C/N	16,74	29,74	20,41

Mathava Kumar, el al. Found, for a study on green waste, that the starting value for the starting C/N ratio is 52.2. This is due to the fact that green waste is raw and has not been mixed. And for organic household waste the value is 8.85. The nitrogen rate for green waste is 0.8% and for organic waste is 5.35%. The differences are logical given the high nitrogen content for organic waste.

The following table presents the analysis results of the samples at the end of composting.

Table 4: the results of the analysis of the samples at the end of composting

WINDROW	1	2	3
MO%	76.26	73.28	77.57
C %	37,7	42,7	40,88
Ca^{2+} %	0,60	0,52	0,64
Mg^{2+} %	1,49	1,01	1,18
K^{+} %	0,92	0,83	0,94
Na^{+} %	0,25	0,21	0,19
P %	0.322	0.305	0.280
N%	2,1	1,8	1,9
pH	7,98	7,83	7,93
C/N	17,95	23,72	21,52

3.3.3 Microbiological characterization of composts

Research of the total aerobic mesophilic flora (FMAT)

The search for total aerobic mesophilic flora (FMAT) in Samples A1, A2, A3 is carried out by culture on PCA medium and incubation for 24h to 48h at a temperature of 30°C and 44°C. The counting of viable cells only concerned dishes with a colony number between 30 and 300, such as $30 \leq N \leq 300$

For counting of viable cells on solid medium with repetition, the concentration in number of cells in the suspension is expressed by the following formula (Eq.1):

$$N = \frac{\sum of\ UFC\ counted}{Taking\ Volume} \times Dilution\ Factor \quad (1)$$

Where: Σ Colonies - Sum of interpretable colonies for each dilution

Search for yeasts and molds

The search for yeasts and molds in Samples A1, A2, A3 is carried out by culture on PDA (Potato Dextrose Agar) medium and incubation for 72 hours at a temperature of 25°C.

Search for Staphylococcus aureus

The search for Staphylococcus aureus in Samples A1, A2, A3 is carried out by culture on Baird-Parker medium and incubation for 72 hours at a temperature of 37°C.

Search for Salmonella- Shigella

The search for Salmonella-Shigella in Samples A1, A2, A3 is carried out by culture on Salmonella-Shigella agar medium and incubation for 72 hours at a temperature of 37°C.

Search for total/faecal coliforms

The search for total/faecal Coliforms in Samples A1, A2, A3 is carried out by culture on Macconkey medium and incubation for 72 hours at a temperature of 37°C and 44°C.

The result obtained for the three compost samples is shown in the table:

Table 5: microbiological analysis results of composts

	A1	**A2**	**A3**
FMAT at 30°C (UFC/g)	714.10^6	3780.10^7	445.10^7
FMAT at 44°C (UFC/g)	940.10^6	827.10^7	245.10^6
Yeasts and molds (UFC/g)	770.10^9	305.10^8	55.10^6
Staphylococcus aureus (UFC/g)	Absence	Absence	Absence
Salmonella-Shigella (UFC/g)	Absence	Absence	Absence
Total coliforms (UFC/g)	670.10^2	309.10^3	190.10^3

The results of the microbiological analyzes show that the content of the total aerobic mesophilic flora is different between the three windrows examined according to the two temperatures, that's to say it depends on the nature of each windrow and its organic composition. Then we clearly note the presence of a significant load of the FMAT at the temperature 44°C compared to that of the temperature 30°C then the evolution of the temperature during the composting is a first index which reflects the degree of degradability of composting and the latter shows intense microbial activity resulting from the degradation of simple molecules present in the substrate.

The majority of yeasts and molds are mesophilic and develop between 5°C and 37°C with an optimum temperature of 25°C to 30°C. As our results show, we can clearly see that the highest fungal biomass load is recorded in windrow 1, this can be explained by the presence of manure, fungi help break down hard debris into palatable pieces, then bacteria can take over and degrade the broken-down pieces. The richness of the compost in mushrooms makes it possible to improve the biodiversity of overexploited soils. Indeed, soil amendment with compost induces an increase in the populations of soil microorganisms by a factor of 1000 (Larbim, 2006).

Colonies of Staphylococcus aureus are black and shiny, with a fine white border, surrounded by a clear zone. They are characterized by the formation of black colonies (reduction of tellurite to tellurium), shiny, convex, surrounded by a halo of clarification of egg yolk. In our case we notice the total absence of these germs in the compost which can be explained by the good respect of the rules of the design of the compost.

The microbiological analysis revealed that the three compost samples are devoid of Salmonella-Shigella SSA (pathogenic microbial group), which testifies to the maturity of the compost.

Table 6: Microbiological criteria according to compliance with the NFU 44-051 standard

	Composts NFU 44-051
Viable helminth eggs	Absence in 1.5 g MB
Salmonella	Absence in 1 g MB (excluding market garden crops) or 25 g MB (market garden crops)

3.2 Study of the kinetics of the compositions of each windrow

We notice that all the temperature values increase slightly with time and this for all the windrows. This increase is due to the high biological activity in the composts, linked to the degradation of easily degradable organic matter.

In the composting that we did, we notice that the pH values are almost similar between all the windrows (~8) and that they remained almost constant during the first month of composting. During the process, there was an increase in pH followed by a decrease in the final phase until stabilization.

The composts studied are characterized by their richness in terms of nutrient content, in particular nitrogen, potassium and phosphorus. The same thing for the other elements and more specifically the calcium content.

The organic matter content is higher than the minimum content (30%) required by the standards. The other criteria concerning the levels of fertilizers are also satisfactory. Thus, the three composts meet the requirements of the standards for use as an organic amendment.

3.3Maturity of composts

The maturity of the compost is an important characteristic to consider when assessing its quality. There are many methods for evaluating the maturity of compost, because it is impossible to find a single test that can validly evaluate this criterion. The use of several indicators such as the C/N ratio, the germination test, the growth of plants, etc., is necessary.

The C/N ratio controls the microbiological balance of the soil. This is the parameter most commonly measured to assess the maturity of compost. It has been established that a C/N ratio greater than 8 corresponds to mature compost (NFU 44-051). The C/N ratios determined in this study varied from 17.95 to 21.52 (Table 7) and thus show that these composts were almost mineralized. This confirms that the compost produced was mature.

Table 7: C/N ratio for the three composts

Compost	C %	N %	C/N
Windrow 1	37,7	2,1	**17,95**
Windrow 2	42,7	1,8	**23,72**
Windrow 3	40,88	1,9	**21,52**

For the windrow A3, which consists only of green waste, we notice that there is a small difference in terms of the content of fertilizing elements, this difference is also noticed in terms of the evolution of the temperature. However, these differences have no effect on the maturity of the compost and therefore the final quality of the compost intended for the organic amendment.

Thus, the analysis results showed that, despite the difference in origin of the composts, the nutrient contents remain similar. Consequently, this study allowed us to reach the best composition based only on green garden waste to develop a mature compost ready for use as an organic soil amendment, without resorting to the addition of other matters outside the Garden.

4 CONCLUSIONS

Humanity is currently challenged to produce profitable and sustainable processes that do not affect the environment, hence the need to develop products that will contribute to improving the productivity of the agricultural sector, and consequently to soil improvement and protection. There is a clear need for research and development aimed at designing and developing applications of biotechnology to improve soil conditions, of which composting is one of the most viable alternatives.

This work aims to integrate the research site into a circular economy approach, aimed at recovering green waste from the Botanical Garden of Rabat through the design and construction of a composting platform. Indeed, the results obtained allowed us to develop an optimal composition of compost, based only on green waste and capable of being a quality organic amendment.

The methodology used in this article can be replicated at the farm level, allowing them to close the carbon cycle and protect their environmental and economic sustainability.

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