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ARTICLE

Evolution of Macrofauna Structure during the Composting Process of Household Waste

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ABSTRACT

The fact that Morocco is an agricultural country and the large volume of biodegradable waste produced by the population make composting so important. The degradation of organic matter is facilitated by faunal and floral macro and micro-organisms that act in different stages of maturation; studies on this fauna are quite rare both nationally and internationally. On a sample of two tons of household waste, we documented invertebrates that colonized compost heaps and then assessed the changes in the structure of the invertebrate population during the different phases. Our study revealed the presence of several zoological groups colonizing the compost heaps during the different composting phases; we noted the presence of: (1) Macroscopic invertebrates, in order of number of individuals: insect larvae, ants, earthworms, sowbugs, spiders, springtails, and millipedes, and (2) Microscopic invertebrates, the most abundant in terms of individuals: mites and nematodes. As for the order of appearance, we observed that insect larvae were the first to colonize the compost heap

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ARTICLE INFO
Received: 15 September 2024 | Revised: 3 November 2024 | Accepted: 12 November 2024 | Published Online: 15 January 2025
DOI: https://doi.org/10.30564/jees.v7i1.7292

CITATION
Loubna, M., Loukili, A., El Houssaine, B., et al., 2025. Evolution of Macrofauna Structure during the Composting Process of Household Waste. Journal of Environmental & Earth Sciences. 7(1): 632–640. DOI: https://doi.org/10.30564/jees.v7i1.7292

from the very first days of installation, followed by woodlice observed during the thermophilic phase and disappearing towards the end of the process. Earthworms were observed during the end of the thermophilic phase, while springtails were observed more during the cooling and maturation phases. Our study revealed the presence of a good quality of fauna during the composting process, which are indicators of good compost quality and play a major role in the circulation of nutrients, thus ensuring the provision of essential elements for plant nutrition.

Keywords: Household Waste; Fauna; Evolution; Composting; Quality of Compost; Morocco

1. Introduction

Africa has many natural and mineral resources, which form the backbone of the continent's economy. These resources are spread across the continent, on land, along the coasts and even in the deep ocean. In recent decades, the pace of industrialization and urbanization has increased in parallel with the growth of the human population, considerably increasing the threat posed by pollution. The cause of pollution, which translates into unsustainable resource management, is overexploitation, or in other words, the excessive or negligent use of resources [1].

Demographic, economic and urban growth are at the root of various sources of environmental pollution. Household waste and urban effluent are the main causes of water and soil pollution. This waste poses numerous ecological problems, including undesirable smells, insect proliferation, air pollution, global warming and even some explosions [2]. Effluent discharge standards for different types of waste have not been established in most African countries. Biodiversity is affected by all these pollutants, as they force species to migrate, intoxicate or suffocate in the polluted zone to survive [1].

In Morocco, several studies have recently been conducted on the sources of pollution in many rivers, which indicate the quality deterioration of the water due to various human activities [3–5]; the biological recovery of organic matter contained in household waste through composting is the most promising option compared with other waste disposal methods, since the latter are rich in compostable organic matter with a sufficiently high moisture content [6, 7]. Maintaining compost quality plays an essential role in any agricultural use of compost; compost organisms, on the one hand, provide a more reliable and relevant measure of ecological risks because they integrate the full range of physical and chemical conditions of compost and the bioavailability of pollutants [8, 9] and, on the other, play a very important role in the soil fertilization process through the mineralization of organic matter [10].

Among the living beings active in the composting process, we can differentiate between visible and invisible fauna, which present different sensitivities to the environmental conditions prevailing in the heaps: humidity, temperature, and aeration. The diversity of this fauna is related to the nature of the organic matter, the compost's stage of maturation, the mode of humification, and the compost's physico-chemical characteristics [11].

There is little or no research on these subjects at the national level, whereas knowledge of these populations provides insights into the quality of the product and the course of the process.

Our work consists of firstly evaluating the complete list of invertebrates that colonize this environment and secondly highlighting the variations in the structure of the population during the different stages of composting.

The results of this study will provide crucial data to assess the ecological health of household waste compost and guide conservation and environmental management policies. By contributing to the documentation of Moroccan compost fauna, this research will also strengthen the overall understanding of biodiversity in the rich and diverse region.

2. Materials and Methods

2.1. Study Environment

Today, landfills are the most common form of waste disposal in Third World countries, and in Morocco they are the source of a few environmental and, above all, human health hazards for the populations living near these dumps. Rainwater and water from organic garbage (peelings and food scraps) are discharged and encounter toxic substances such as heavy metals and microplastics, which are found in this mixed waste[9–12]. We can recycle our waste and eliminate all these negative effects into healthy compost that is useful for agriculture, the soil and the environment.

The city of Kénitra, a coastal town in northwest Morocco, 10 km from the mouth of the Oued Sebou, enjoys a warm-summer Mediterranean climate, which is a type of temperate climate. During the year, the temperature ranges from 8 °C to 28 °C and is seldom lower than 5 °C or higher than 33 °C.

Kenitra is separated from the Atlantic Ocean by a barrier of coastal dunes and the Sebou estuary. It is the capital of the Gharb region and one of the Kingdom's richest cities, founded in 1912. According to projections by the Centre d'Etudes et de Recherches Démographiques (CERED), the population of Kenitra province will rise from 878,085 in 2004 to around 1,007,300 in 2014. Agriculture, forestry, fishing, and the agri-food industry remain key sectors of economic activity in the region.

Household waste from the city of Kenitra is dominated by a fermentable organic matter (vegetable and fruit residues) with a very high moisture content; the treatment technique adopted is heap composting. Our study was carried out on a two-tonne sample of the city's waste and involved mixing the waste to be composted and arranging it in a heap 2 m in diameter and 1 m high (**Figure 1**).

Figure 1. Setting up the heap after sorting the waste.

The collected waste first underwent pre-treatment (sorting, screening and shredding) aimed at homogenizing, refining and moistening the product intended for composting. The heap was made up of two tonnes of urban waste from the "Ouled Berjal" landfill located within the urban perimeter, 3 km north of the city of Kénitra, in a loop of the Sebou wadi. The collected waste first underwent pre-treatment (sorting, screening and grinding) to homogenize, refine, and humidify the product intended for fermentation. The composting technique was carried out at the Faculty of Sciences of Kenitra.

The composition of urban waste intended for composting depends on the efficiency of the sorting carried out, both during collection and at the entrance to the composting unit.

2.2. Sampling

During composting, samples of waste or compost were taken each time the waste heap was turned. A sample of 0.5 kg of material in sterile bags was taken 3 times at different levels of the heap (center and peripheries) to obtain a representative sample used for laboratory analyses.

After the pile was placed, turning was carried out on days 1, 2, 4, 8 and 16, to ensure good aeration and enable aerobic fermentation. Subsequently, the turning was carried out at the end of each month until the mature compost was obtained at 6 months[10, 11].

After 6 months of reaching the maturity degree, the compost was subjected to a physicochemical, empirical, and biological analyses to evaluate its agronomic quality.

Fauna, including birds, insects, crustaceans, worms, and rotifers, thrive in the waste, attracted by the odours of the food they find, leading to degradation of the waste and fragmentation of organic matter to be consumed by other organisms.

To understand the biodiversity of the ecosystems that prevailed during the process of composting household waste, it was essential to identify the taxonomic groups of the fauna.

The diversity of communities calls for sampling methods: different sampling methods were used to capture organisms in their environment. They were based on several community characteristics: the size of the individuals, their position in the compost heap (surface, depth), the environment of the heap occupied (core or outskirts) and feeding conduct of the fauna[13, 14].

Macro-invertebrates of the pile were sampled using a method by hand; for micro-invertebrates, sampling was carried out for each heap on a 20 × 20 cm square surface from the surface to the ground, at random points on the heap (core or outskirts), and was repeated each week of the composting period.

Sampling was carried out using the TSBF (Tropical

Soil Biology and Fertility) method[15, 16].

Samples were stored in airtight bags. In the laboratory, small quantities of compost were taken, crumbled and spread out in a plastic tray to identify all the macroorganisms present. Zoological groups were separated in pillboxes containing 70% alcohol. Species within each group were determined, then counted (only whole individuals and cephalic parts were considered)[17].

For micro-invertebrate extraction: using the Berlese apparatus, consisting of a funnel on which a grid was placed. The sample was dried on the grid, heated by a lamp to accelerate the process[18, 19].

2.3. Identifying Systematic Groups

All species collected from each sample will be stored in vials with 70% alcohol. So-called functional classifications are widely used in fauna ecology, such as the ecological categories of earthworms, springtails, nematodes, etc.

The individuals were sorted under a binocular magnifier (20×/40×/Optika SFX-3) or optical microscope (SWIFT SW350T, 40×-2500**)** (for the smallest) to observe the morphology and the systematic determination characters of the individual.

The taxonomic groups were identified using determination keys at various levels of taxonomic precision; in some cases, help from specialist colleagues in the department and at the national level was requested for a more precise identification. Individuals belonging to each group were then counted to establish their abundance and diversity for each composting phase[20].

3. Results and Discussion

3.1. Biodiversity of Fauna in Compost Heaps

The living beings active in the composting process can be classified according to their size into two categories: macro-organisms and micro-organisms. These are specialized living beings, which must be provided with the most appropriate circumstances[21]. For this reason, temperature variations can influence the composition of the microorganisms, and consequently the fauna populations and the final product of degradation (**Table 1**).

Table 1. Average variation of physicochemical parameters during composting.

Parameters	Average Value during Mesophilic Phase	Average Value during Thermophilic Phase	Average Value during Cooling Phase	Average Value during Maturation Phase
Temperature	55 ± 1.5	68 ± 1.6	32 ±0.9	31 ± 1.9
pH	6.5 ± 0.2	6.8 ± 0.2	7.8 ± 0.22	8.1 ± 0.22
Humidity	57%	30%	40%	40%
C/N ratio	21 ± 2.24	18 ± 1.72	11 ± 1.37	7 ± 0.56

Table 2 shows the composition (number of individuals per kilogram of organic matter sampled) of our compost heap during the different phases of the process.

In permanent contact with the substrate, they reflect living conditions through variations in the dynamics of the populations that respond to these changes. Whatever their origin, composted waste contains several microorganisms of enteric origin. These include bacteria, viruses, parasites, insect larvae and eggs of various species. What's more, once waste is piled up in the open air, it is invaded by macroorganisms and soil microorganisms and buried deep down[13–21].

The structure and biodiversity of macroorganisms in compost also depend on the type of waste: there are living beings that are attracted by a specific type of waste, and in this case we speak of composting activators[10, 11]; this is why macroorganisms in the composting process have been found to be highly diversified; earthworms (a highly diversified genus) are especially abundant during both thermophilic and cooling composting phases, whereas they are less abundant during the first and last phases. As for insect and diptera larvae, they are very abundant during the first and last phases, especially the larvae of Mochidae, which are very sensitive to temperature increases during the thermophilic phase. Other insects that live in the soil all their lives, such as ants and certain ground beetles, invade the pile as the compost matures.

Sowbugs, myriapods and gastropods colonize the pile in roughly constant numbers throughout the four composting phases[22, 23].

The microfauna consists of organisms smaller than 0.2 mm; several species of nematodes, springtails and mites were represented by hundreds of millions of individuals and were present during all phases of composting; for springtails, there was an increase in the number of members during the phases of the process, with a small number during the first and reaching 6,276 individuals per kilogram during the last phase; this result is justified by the fact that springtails feed mainly on decomposing organic matter. Their burrowing and fragmentation activity increased with the decomposition of plant waste into smaller pieces, thus accelerating the overall composting process.

Table 2. Mean abundance of fauna during composting phases.

Fauna	Average Count during Mesophilic Phase	Average Count during Thermophilic Phase	Average Count during Cooling Phase	Average Count during Maturation Phase
Ground glass (*Lombricus terrestris*)	Absent	24 ± 1.72	32 ± 2.468	02 ± 0.31
Sowbugs (*Armadittidium vulgare*)	45 ± 6.32	67 ± 6.27	20 ± 2.34	5 ± 0.62
Flies and insect larvae	1,083 ± 105.82	19 ± 5.72	806 ± 92.21	600 ± 12.82
Ants	25 ± 2.61	521 ± 52.05	263 ± 12.83	529 ± 106.35
Slugs (*Arion rufus*)	Absent	Absent	Absent	02 ± 0.18
Cepheon larva (*Cetonia aurata*)	Absent	Absent	Absent	03 ± 0.25
Forficuta auricularia	04 ± 0.56	02 ± 0.31	Absent	Absent
Springtails	159 ± 4.52	2,852 ± 10.87	5,754 ±76.89	6,276 ± 614.74
Mites	Up to 10,000	Up to 10,000	Up to 10,000	Up to 10,000
Nematodes	Up to 1000	Up to 1000	Up to 1000	Up to 1000

We then observe a significant increase in organisms responsible for digesting and degrading organic matter. This is like the results explained by the simple fact of the nutritional competition they exert, as well as the secretions of antibiotics and enzymes [13–24].

By crushing organic matter, macro-organisms increase the surface area of the composted material; this work is carried out by small animals, in particular: sowbugs, millipedes, mites, springtails, midge larvae, beetle larvae, chafer larvae and gastropods. Without them, organic matter would be reduced much more slowly [21–25].

3.2. Evolution of Fauna Community Structure during Composting

All the animals involved in composting form the basis of the material recycling system in all ecosystems: they are represented by microorganisms and macroorganisms. It should be noted, however, that during the composting process, the composition of the organic products in the material changes, as do the living communities [23].

In this section, we have followed the evolution of three of the most important species: earthworms, sowbugs, springtails, and mites. The choice of these three groups was based on the fact that they provide us with information on the structural conditions, activity and maturity of the compost, and covering all phases of the composting process.

3.2.1. Earthworms

Earthworms are an important part of the soil macrofauna, dominating the biomass of most terrestrial ecosystems.

They are characterized by an elongated, circular anatomical structure. Their bodies are made up of a succession of 60 to 200 rings, each with an almost identical anatomy and frequently repeated. They live and feed on the surface, with a small to medium adult size (10–30 mm) and a silvery-red hue. These species are distinguished by their rapid movements in response to disturbances. Our specimens have morphological and anatomical features that are clearly similar to those of Eisenia fetida. The systematic classification of our species is:

Kingdom: Animalia
Phylum: Annelida
Class: Oligochaeta
Order: Haplotaxida
Family: Lumbricidae
Genus: Eisenia
Species: *Eisenia fetida* (Bouché, 1972);

Earthworms live naturally on the surface of the soil, in the piles of organic matter on which they feed. Their role is to decompose the organic matter accumulated on the soil surface. They naturally migrate in large numbers towards the compost heaps and can number up to 1,000 individuals per kilogram of compost in humid areas [26].

In our sample, earthworms are absent from the middle of the heap, with only a few individuals appearing at the periphery during the first two weeks of the process (**Figure 2**).

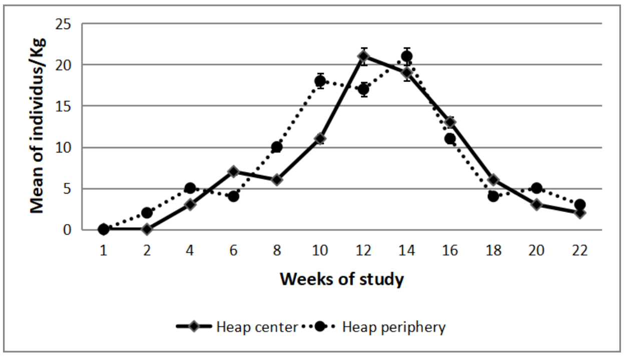

Figure 2. Evolution of earthworm's during composting for this study.

This is due to the rise in temperature during the thermophilic phase, which reaches a maximum of 70 °C after 16 days of treatment. Thereafter, an increase in the number of individuals is noticeable from week 6 to week 15, which could be explained by the fact that the treatment enters a significant cooling phase. This phase is characterized by a decrease in temperature and an increase in humidity, which is preferable for earthworms. At the end of composting, there appears to be a reduction in the number of individuals, indicating the depletion of the composting mass in biodegradable organic matter. These results are in line with those [23–27] who found that worms are less numerous, or even non-existent, at certain stages of the composting process, acting at the beginning of the process, on elements that are not very decomposed. It's only when the temperature drops below 30 °C that worms colonize the compost. At the end of the maturation phase, there are also fewer worms in the compost, because the organic matter has already decomposed, and the worms no longer have as much material to live on. The more mature the compost, the fewer the worms [28].

3.2.2. Sowbugs

As with earthworms, sowbugs invade the middle and fringes of the pile from the second week onwards, and during the process the number of individuals increased, reaching a maximum in the 8th week in the middle and fringes. The number of individuals then decreases until the 14th week, with a second increase from the 16th week. Numbers then fluctuated until the end of composting, increased by watering the pile, or reduced by turning (**Figure 3**).

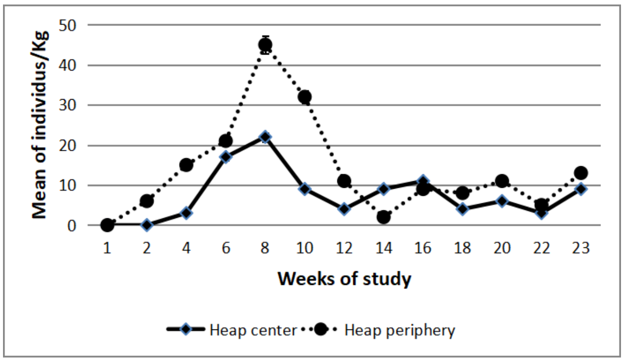

Figure 3. Changes in woodlice during composting study.

Our results are in line with those of Derron and Blandenier [29], who reported that at the start of composting, during the decomposition phase, micro-organisms are active and are accompanied by larger organisms: earthworms, woodlice, mites, and springtails, which will continue to decompose the organic matter.

3.2.3. Collembola

Given the large number of individuals in our sample, we characterized two types of springtails:

- Individuals that live on the surface, with elongated, hard bodies covered in grayish hairs. They have a head, a thorax composed of three segments, and an abdomen with a jumping organ. What looks like the order of *Entomobryomorphs.*

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Hexapoda
Class: Collembola.
Order: ***Entomobryomorphes*** (Schäffer, 1896).

- Individuals that live a little deeper, globose in appearance. Their antennae are very short, the length of the antennae does not exceed half the size of the head, the antennal segments of antennae 3 and 4 are not clearly separated. Empodium with a distinct projection at its base, ocelli absent, presence of furca.

Kingdom: Animalia
Phylum: Arthropoda
Subphylum: Hexapoda
Class: Collembola.
Order: ***Neelipleones*** (Massoud, 1971).
Family: Neelidae (Folsom, 1896).

- The number of springtails was a very interesting indicator, as it provides information on the structural conditions and activity of the compost [30]. Analysis of **Figure 4** shows that after 2 to 3 weeks of composting, the springtails were found in the samples analysed.

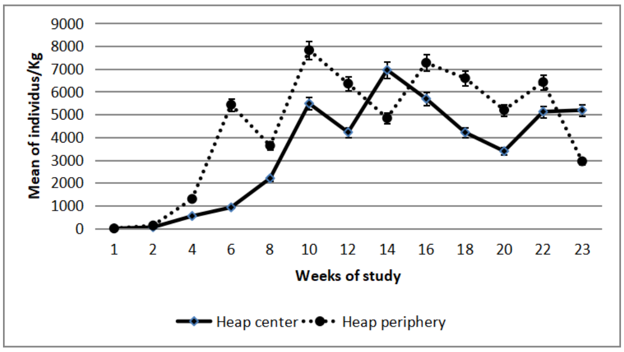

Figure 4. Changes of springtails mean number during composting in this study.

In general, they appeared in greater numbers only after the heap had heated up the most. At the middle of the heap, this average number of springtails reached its maximum after 10 weeks, and at the periphery it peaked at 6 weeks. Then, from the 11th week to the 23rd week, the number of individuals remained variable, with 3388 individuals and 7266 individuals as the minimum and maximum extreme values.

The evolution of springtails during composting depends on temperature, fermentability, initial humidity, C/N ratio, pH and composting mass. It also depends on the frequency and quality of turning, heap dimensions and climatic conditions. These results are in line with those of Derron and Blandenier [29], who pointed out that the number of springtails increases in organic matter during hot fermentation.

3.2.4. Microfauna

Microfauna are micro-organisms visible only with a binocular magnifying glass or microscope, ranging in size from 0.002 microns to 2 mm. The biodiversity of the microfauna in compost is much greater than that of the soil, due to the higher concentration of nutrients for living organisms. These organisms are the real players in composting, as they are the ones who transform organic waste into compost.

Bacteria, protozoa, yeasts, and certain fungi that form filaments, such as moulds that appear particularly on fruit and other damp waste, as well as mites, nematodes and very small species of springtails.

In this work, we have concentrated solely on mites and nematodes, as they are larger and more easily visible with a binocular magnifying glass, making them easier to count and observe.

Several red, brown, orange, or brown mites were observed during the composting process; their number can reach 10,000 individuals of mites per kilogram of compost. They can be present in every composting phase, but in this work, we observed a great proliferation of mites when the compost was left without turning. This means that turning the compost decreases the number of mites in the compost; the same results are observed by Ducasse [28], who justifies that their presence in large numbers in the compost is perhaps a sign of anaerobic decomposition, since they can live for some time in these conditions, requiring turning or aeration of the compost heap.

4. Conclusions

This work enabled us to identify several groups of animals that live in compost and take part in the composting process, which were reported for the first time in Morocco: the ground glass: *Eisenia fetida* (Bouché, 1972); the woodlouse *Armadillidium vulgare* (Latreille, 1804); and springtails of the Family Neelidae (Folsom, 1896) and Order Entomobryomorphes (Schäffer, 1896).

Millions of animals come up from the soil to the waste heap, attracted by the food concentrated in the waste and compost; their presence is indicative of good compost quality, since animals are responsible for the decomposition of organic waste. It is for the survival of all this fauna that the pile must always be stirred to ensure good aeration.

The structure and biodiversity of the animal organisms in compost also depend on the type of waste. There are living beings that are attracted by a specific type of waste, and in this case, we speak of composting activators.

The diets of compost fauna vary in strictness. They can be mixed (polyphagous species) depending on available resources and needs or change according to the stage of development.

It can be said that there is a link between the nature of the waste and the populations of living organisms.

The appearance of a given type of compost is determined by the nature of the zoological and microbial groups present (presence or absence of earthworms, mycelia resistant to biodegradation, etc.), which in turn depend on the nature of the waste and environmental conditions (temperature, humidity, acidity, etc.). Each of these two levels of dependence has a certain degree of tolerance.

Water and temperature reflect the climate that conditions waste alteration and are the initial determining factors in any composting process.

According to the results obtained during this work, which was carried out in very suitable conditions, we produced a mature compost of good quality (according to the analyses we carried out) and healthy for human health and agriculture.

Author Contributions

M.L. is the main author, who executed the thesis work: waste collection, composting, wildlife collection…; A.L. is the co-director of the thesis, who helped the main author during each stage of the work; B.E.H. is the PhD student, who participated in the execution of laboratory manipulations, especially the statistical study; B.H. is the PhD student, who participated in the promotion of compost on crops in the field; S.Y. is the PhD Student, who participated in the language verification; A.E.H. is the head of laboratory, who participated in the supervision of the work; B.D. is the thesis director, who monitored and directed all the work.

Funding

None. All funding is from the Faculty of Science and the commitment of the authors.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All other information is available from the main author.

Acknowledgments

The work was done within the Faculty of Sciences, Ibn Tofail University. We thank the president of the university and the dean of the faculty.

Conflicts of Interest

The authors declare no conflict of interest for this study.

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