Scientific Papers. Series A. Agronomy, Vol. LXV, No. 2, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

QUANTITATIVE AND QUALITATIVE DIFFERENCES IN OAT PRODUCTION (*Avena sativa* L.) GENERATED BY THE TYPE OF COMPOST USED AS FERTILIZER

Imre-Lóránd SIKLÓDI[2,1], Georgiana-Andreea IGNAT[1], Attila TAMAŞ[1], Mirela-Elena DUŞA[1], Vasilica STAN[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, 011464, Bucharest, Romania
[2]Integrated Waste Management Center, Borosneu Mare, Covasna District, administrated by S.C. ECO BIHOR S.R.L, Oradea, Romania

Corresponding author email: siklodi.l@ecobihor.ro

Abstract

Interest in composting biodegradable organic waste has grown significantly in recent years in Romania. An important role in stimulating this interest was played by the integration in the European Union (EU) and the acquisition of the European legislation on waste management but also the pressure of the civil society to improve the environment quality. Thus, more and more composting centers were developed, and a composting law was adopted. Composting of the organic fraction of municipal solid waste (OFMSW) is of great interest. However, composts can present certain risks (heavy metals and even pathogens) coming from raw materials or the way the composting process is conducted. Therefore, a rigorous approach to compost quality is needed in relation to specific standards, especially when they are to be used as amendments to agricultural soils. This paper presents the results of a study in which the effects of six composts on a test plant, oat (Avena sativa L.), were compared in order to evaluate the impact of the waste collection method and the composting method on the composts quality and their agronomic value.

Key words: *compost quality, heavy metals, composting method, source separate collection.*

INTRODUCTION

According to Directive 2018/851/PE, CE, “municipal waste” means “mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, bio-waste...”. Therefore, an important component of them is represented by „bio-waste”, which means “biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food processing plants” (Directive 2018/851/PE, CE). Bio-waste represents the largest component of municipal waste in the European Union (EU) reaching 34%, and its recycling is essential to meet the EU objective of recycling 65% of municipal waste by 2035 (EEA, 2020). The fulfilment of this objective is intended to contribute to “protecting and improving the quality of the environment to protect human health, to ensure the prudent, efficient and rational use of natural resources, to promote the circular economy principles, to increase the use of renewable energy, to increase energy efficiency, to reduce the Union's degree of dependence on imported resources, to create new economic opportunities and to stimulate long-term competitiveness” (Directive 2018/851/PE, CE).

In Romania, the concern of the population and the authorities for the separate waste collection and their sustainable management has grown more and more in recent years. At the same time, a growing interest is paid to the prevention of waste production, the reduction of amounts, their reuse and recycling in the energy and material resources diminishing conditions.

According to statistics, in 2020, in Romania a municipal waste production of 287 kg/capita/year was registered, i.e. a decrease of 13.34% compared to 2005 production (383 kg/capita/year), way below the European average (28 + 3) of 2020, which reached 505 kg/capita/year (EUROSTAT, 2022a). However, in the same year 2020, the municipal waste recycling rate was only of 13.7% (EUROSTAT, 2022b).

The biodegradable organic fraction is an important component of municipal solid waste, having a complex composition, seasonally unstable, which is dependent on people's lifestyle, with differences especially between urban and rural lifestyles. Bio-waste has a high potential to be integrated into the circular economy. It can be recycled through anaerobic digestion (with biogas production) and through composting (aerobic digestion). Composting has become a key element of integrated waste management (Vaverkova et al., 2020) being one of the friendliest technologies for managing the organic fraction of municipal solid waste (Barrena et al., 2014) as well as a cost-effective (Soobhany, 2018; Vaverkova et al., 2020) and efficient method (Jara-Samaniego, 2019). It leads to obtaining a valuable material compost, which is rich in organic matter and nutrients (Duong et al., 2013; Viaene et al., 2016) and can be used for improving soil physico-chemical properties and fertility (Solaiman et al., 2019; Vaverkova et al., 2020). Moreover, the increase in the inorganic fertilizers production costs, as well as the effects of their excessive use on the environment and the climate (Solaiman et al., 2019) increase the interest in bio-waste composting and the agronomic value of compost.

Currently, in Romania, there are several integrated waste management centres that managed to implement composting projects on an industrial scale, but which face obstacles that limit the quality of the final product (Siles-Castellano et al., 2020), as well as certain barriers to the compost utilization. One of the most important obstacles, especially in large urban agglomerations, is the centralized collection, without waste separation at source. In centralized collection, OFSMW is difficult to separate, and the separation operation is very expensive. At the same time, biodegradable waste alters the state of the other types of waste that can be recycled in different sectors. Finally, in order to use the compost in agriculture, regulated quality standards are necessary. On the other hand, in the rural environment, where people have gardens and spaces where they can organize and handle bio-waste for composting and where collection can be done with a thorough separation at the source, this method of managing biodegradable waste, efficient and sustainable (Vasquez and Soto, 2017) can be a way to reduce the administrative costs generated by centralized waste management, which would reduce the pressure on waste management centres and lead to obtaining a very good quality compost. Nowadays, few measures were taken to guide and raise the awareness of the rural population. There is, however, a growing interest in OFSMW composting.

The quality of the compost can be affected by biological factors such as the presence of human and animal pathogens and by chemical factors that can cause phytotoxic effects (Barral and Paradelo, 2011; Paradelo et al., 2020). Among the chemical factors, the presence of heavy metals (cadmium-Cd, copper-Cu, chromium-Cr, nickel-Ni, lead-Pb, zinc-Zn) is frequently mentioned (Barrena et al., 2014; Kupper et al., 2014; Cesaro et al., 2019; Siles-Castellano et al., 2020). These factors could affect the agronomic value of the compost and its agricultural utilization and would increase the risks for the environment, people, and animals. Achieving a good level of compost quality depends on several factors, and source separation is one of the most important (Rodrigues et al., 2020). That is why the process must be managed in such a way so that a high-quality compost is obtained and that its use is accompanied by benefits and not by negative effects on the environment (Barena et al., 2014).

The purpose of this study is to evaluate the quality and test the agronomic value of some composts. The effects of composts on plants (plant growth and development, epigeic biomass production, heavy metal content) and soil (pH, organic carbon, macro- and micronutrient and heavy metal content) were monitored in the study.

MATERIALS AND METHODS

Compost. In this study, 6 types of compost were used, as follows:

1. Poultry manure + wheat straw compost (3:1) - PMWSC - (12-month-old) produced in a household composter;
2. Poultry manure + vegetable food waste compost (3:1) - PMFWC - (12-month-old) produced in a household composter;
3. Industrial compost resulted from OFMSW after centralized separation within an integrated waste management centre - C1_OFMSW (9-month-old);
4. Experimental compost resulted from OFMSW after centralized separation - C2_OFMSW (15-month-old); small amounts were composted, in specially constructed containers (approx. 500 kg in a container);
5. Experimental compost resulted from OFMSW after centralized separation - C3_OFMSW (18-month-old); small amounts were composted, in specially constructed containers (approx. 500 kg in a container);
6. Household compost resulted from source separated bio-waste (biodegradable waste from garden and kitchen) - HHC, produced on a rural household platform (12-month-old).

The soil used in these experiments is of red preluvosoil type, coming from Moara Domnească Teaching and Research Station of the University of Agronomic Sciences and Veterinary Medicine (UASMV) of Bucharest, located in a Sylvosteppe ecological area of Romanian Plain. Before making the mixtures, soil and compost samples were taken for their physico-chemical characterization (Table 1).

Table 1. The physico-chemical characteristics of soil and compost used within experiments

Soil and compost parameters	Soil	PMWSC	PMFWC	C1 OFMSW	C2 OFMSW	C3 OFMSW	HHC
pH	5.89	7.14	7.1	9.18	8.26	8.49	8.36
Moisture (%)	19.3	47.21	42.69	22.22	31.75	41.86	44.64
Dry matter (%)	80.7	52.59	56.31	77.78	68.25	58.14	55.36
C_org. (%)	2.02	14.92	13.62	18.19	15.46	15.8	9.71
C:N	9.35	11.39	10.72	13.38	10.24	9.88	9.23
Nt (%)	0.22	1.31	1.27	1.36	1.51	1.6	1.04
$N\text{-}NO_3^-$ (mg kg^{-1}d.m.)	28.67	229	136	19	195	197	910
$N\text{-}NH_4^+$ (mg kg^{-1}d.m.)	9.12	59.33	53.67	422	28	35	86
P (%)	0.16	1.47	1.62	0.57	0.82	0.9	0.46
K (%)	na*	1.23	1.48	3.38	2.32	2.53	1.48

*not analized.

The soil had a pH (5.89) that characterizes a weak-acidic reaction (Blaga et al., 2008), and the C:N ratio was 9.35. Four of the studied composts had pH values that characterize a neutral to slightly alkaline reaction (Blaga et al., 2008), in ascending order, PMFWC<PMWSC<C2_OFMSW<HHC which is in agreement with the values mentioned by De Bertoldi (1983), and two of them had a reaction from moderately alkaline (Blaga et al., 2008) to alkaline (Mustin, 1987), C3_OFMSW<C1_ OFMSW. The dry matter content was over 50% in all composts, organic amendments having to respect a minimum of over 30% dry matter (NF U 44051, 2006). After analysing the $N\text{-}NH_4^+$ content as an index of maturity (Brinton, 2000), it can be said that four of the composts (PMWSC, PMFWC, C2_OFMSW and C3_OFMSW), which had $N\text{-}NH_4^+$ contents between 28 and 59.33 mg kg^{-1}d.m., can be considered very mature, and the other two, which had a $N\text{-}NH_4^+$ content of 86 mg kg^{-1}d.m. (HHC) and, respectively, 422 mg kg^{-1}d.m. (C1_OFMSW), can be considered mature. The maturity of the composts is also revealed by the C:N ratio. The C_org. content was different in the 6 composts, the lowest being of 9.71% (HHC), and the highest of 18.19% (C1_ OFMSW), while the total nitrogen content (Nt) exceeded 1% of the

dry matter in all composts, which corresponds to the interval mentioned by Azim et al. (2018) but also to the French norms (NF U 44051, 2006) for organic amendments. Unlike the rest of the composts, the compost obtained under domestic conditions had a $N\text{-}NO_3^-$ content of 910 mg kg^{-1}d.m.

The results of the chemical analysis of the heavy metal content (Table *2*) of the 6 composts were compared with the limits imposed by the German standards for Class I and Class II (Biowaste ordinance) and with the limits imposed by Regulation 2092/91/EC. The following were revealed: i) the method used for Cd analysis did not detect Cd presence in any of the composts; ii) PMWSC and PMFWC composts can be included into Class I of quality according to German standards, except for the Cr content that exceeds even the Cr_tot content limit imposed for Class II; iii) all three composts obtained from OFMSW exceed the limits imposed by German standards for Class II for Cu, Cr_tot content, and C2_OFSMW and C3_OFSMW also exceed the Zn content limit for the same class; iv) household compost resulted from bio-waste (biodegradable waste from garden and kitchen separately collected) – HHC belongs to Class I; v) all evaluated composts had Ni content below the limit imposed by the German standards for Class I and Pb content below the limits imposed by EC Reg. 2092/1991.

Table 2. Heavy metals content in soil and compost used within experiments

Soil and compost parameters	Soil	PMWSC	PMFWC	C1_OFMSW	C2_OFMSW	C3_OFMSW	HHC	Biowaste ordinance (Germany)***		EC Reg. 2092/1991 (compost from source separated Biowaste)***
								Class I	Class II	
Cd (mg kg^{-1}d.m.)	nd**	nd	nd	nd	nd	nd	nd	*1*	*1.5*	*0.7*
Cu (mg kg^{-1}d.m.)	26.8	44.1	47.9	133	119	121	34.5	*70*	*100*	*70*
Cr_tot (mg kg^{-1}d.m.)	32.5	183.33	126	132	311	341	34.7	*70*	*100*	*70*
Ni (mg kg^{-1}d.m.)	19.6	19.5	26.83	22.1	26.7	24.9	19.9	*35*	*50*	*25*
Pb (mg kg^{-1}d.m.)	12.3	9.93	19.2	20.1	12.6	19.7	10.5	*100*	*150*	*45*
Zn (mg kg^{-1}d.m.)	661	285.67	257.33	400	462	413	351	*300*	*400*	*200*

**not detected with the analysis methods used;
***Heavy metal limits for European compost standards. Final Report. ANNEX 2; JUNE 2004. Table A2-4. Heavy metal limits for European compost standards. Compost from source separated Biowaste.

Experiment organization. The experiment was carried out in greenhouses belonging to UASMV of Bucharest in the spring of 2022, between March and May. All the composts, as well as the soil, were initially sieved through a sieve with 10 mm diameter holes, and a second sieving was carried out with a 6.3 mm diameter sieve. Three mixtures of compost and soil were made for each type of compost, respectively with 25%, 50% and 75% according to the scheme below, as well as a control variant only with soil. A variant with 100% compost was also made for HHC. This resulted in 20 variants organized in 2 replicates.

V1_Soil - 100%
V2_25% soil +75% (g/g) PMWSC
V3_50% Soil + 50% (g/g) PMWSC
V4_75% Soil + 25% (g/g) PMWSC
V5_25% Soil +75% (g/g) PMFWC
V6_50% Soil + 50% (g/g) PMFWC
V7_75% Soil + 25% (g/g) PMFWC
V8_25% Soil + 75% (g/g) C1_OFMSW
V9_50% Soil + 50% (g/g) C1_OFMSW
V10_75% Soil + 25% (g/g) C1_OFMSW
V11_25% Soil + 75% (g/g) C2_OFMSW
V12_50% Soil + 50% (g/g) C2_OFMSW
V13_75% Soil + 25% (g/g) C2_OFMSW
V14_25% Soil + 75% (g/g) C3_OFSMW
V15_50% Soil + 50% (g/g) C3_OFSMW
V16_75% Soil + 25% (g/g) C3_OFSMW
V17_25% Soil + 75% (g/g) HHC
V18_50% Soil + 50% (g/g) HHC
V19_75% Soil + 25% (g/g) HHC
V20_100% HHC.

In the mixtures made, oat (*Avena sativa* L.) was sown on the same day. The seeds germinated after approx. 4 days, and the complete emergence and the beginning of the elongation of the plant stem occurred in 7 days, approximately (Photo 1). Throughout the vegetation period, the growth and development of the plants was monitored, and a sufficient moisture was constantly ensured.

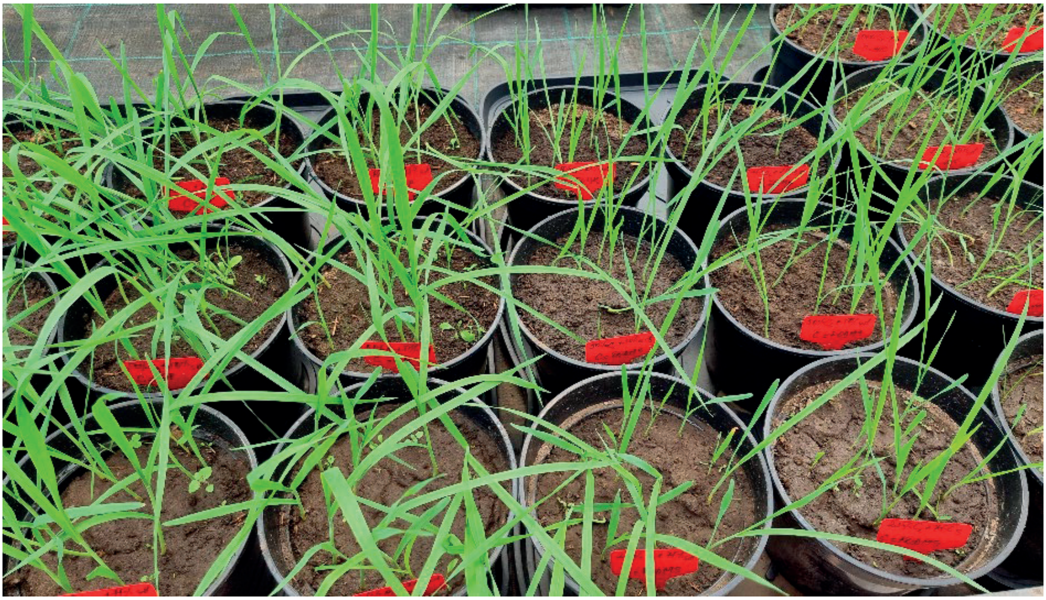

Photo 1. Greenhouse experiment with soil and different composts mixtures grown with oat

Measurements and analysis. The plants were harvested after grain formation and filling and the amount of epigeic biomass was evaluated on variants and repetitions. Plant samples were taken from each variant and chemically analysed for nutrients (N, P, K, Ca, Mg) and heavy metals (Cd, Cu, Cr, Ni, Pb, Zn). Soil samples were taken from the vegetation pots (soil and compost mixtures corresponding to each variant) and the physico-chemical properties were evaluated (pH, moisture, dry matter, organic carbon, N, P, K, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$ and heavy metals in total forms - Cu, Cr, Ni, Pb, Zn). Since no Cd content was detected during the initial physico-chemical analysis of the composts, it was not subsequently analysed in the oat biomass or in the soil and compost mixtures. All chemical analyses, both for soil and for plants, were carried out in the Soil Pollution Control Laboratory of the Institute for Pedology and Agrochemistry in Bucharest according to its own methodology specific to each type of analysis.

Data analysis. All data were analysed as the average of the two replicates performed for each variant.

RESULTS AND DISCUSSIONS

Oat biomass production. All the studied compost and soil mixtures, regardless of the proportion of the compost in the mixture, led to biomass productions above the level of those achieved in the control variant in which only soil was used. The biomass production registered in the variants with compost were expressed in g/pot, and differences compared to the control variant in percentages (Figure 1 a, b, c, d, e, f). Thus, a descending order ranking of the differences registered in the oat epigeic biomass production in the variants where composts were used, compared to the control (soil), looks as follows:

1. in the variants with 75% compost and 25% soil: PMFWC > C3_OFSMW > HHC PMWSC > > C1_OFMSW > C2_OFMSW;

2. in the variants with 50% compost and 50% soil: PMFWC > PMWSC > HHC > C3_OFSMW > C1_OFMSW > C2_OFMSW;
3. in the variants with 25% compost and 75% soil: PMFWC > PMWSC > HHC > C3_OFSMW > C1_OFMSW > C2_OFMSW.

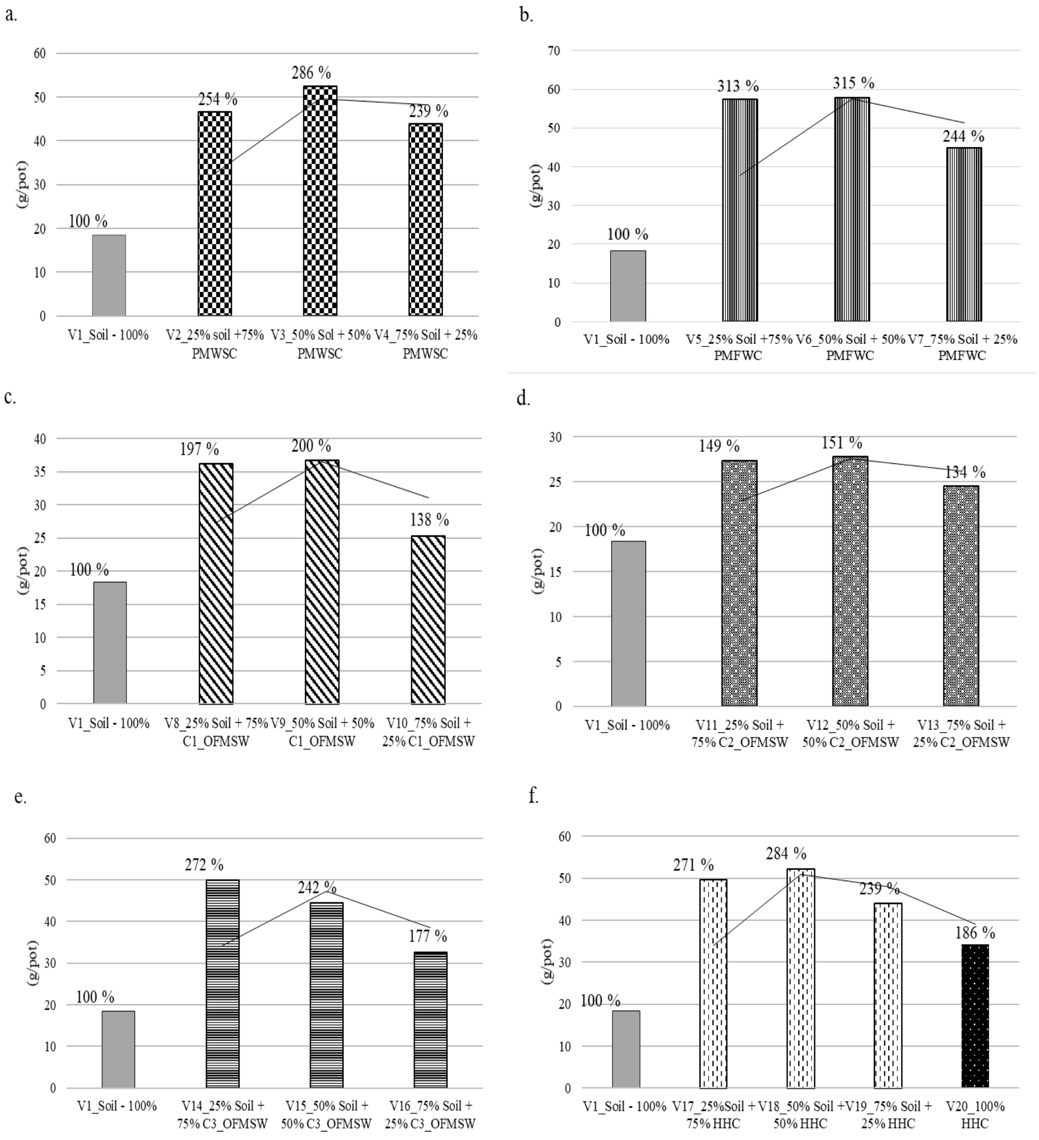

Figure 1 (a, b, c, d, e, f). Epigeic biomass production of oat grown on different soil and compost mixtures

Heavy metal content in epigeic biomass. The results of the chemical analysis carried out on the samples of fresh oat biomass (Figure 2 a., b., c., d.), taken immediately after harvesting (grain filling phase), are presented as the average of the variants. In general, the heavy metal content in plant biomass tended to increase with the proportion of compost in the soil and compost mixture. Thus, the highest Cu content was registered in the two composts based on poultry manure (Figure 2 a) reaching approx. 29 mg kg^{-1}d.m. in the V2 variant (75% PMWSC). However, in most variants, the Cu content in plant biomass was below 20 mg kg^{-1}d.m. and below the control level (100% soil). The lowest Cu content was registered in the variants with C3_OFMSW and in those with HHC. The normal Cu content in plants ranges between 2 and 20 mg kg^{-1}d.m. (Dhaese, 1979; Graham, 1981), and above 20 ppm it becomes toxic. The highest Cr content (Figure 2 b) in plant biomass was registered in the V11 variant (75% C3_OFSMW mixed with 25% soil), respectively approx. 4 mg kg^{-1} d.m., while in the control variant a Cr content below 1.5 mg kg^{-1}d.m. was registered. In most variants, the Cr content was below 3.5 mg kg^{-1}d.m. Chromium levels between 0 and 0.5 mg kg^{-1}d.m. are considered normal, and those above 1.3 mg kg^{-1}d.m. are considered phytotoxic (Dhaese, 1979). The plants grown in the control variant (100% soil) reached a Ni content (Figure 2 c) of 7.63 mg kg^{-1}d.m., and contents below this level were registered in the plants grown in V2 (75% PMWSC), V3 (50% PMWSC), V5 (75% PMFWC) and V15 (50% C3_OFMSW). The role of Ni in the plants mineral nutrition has been described quite recently (Eskew et al., 1983; 1984). However, its normal content in plants would be between 0 and 8 mg kg^{-1}d.m. (Dhaese, 1979), and at concentrations of 40 mg kg^{-1} d.m., Ni is toxic (Impens, 1992). Regarding the Zn content in plants, the samples taken from plants harvested in all compost variants, regardless of its type, had contents that exceeded the control variant. At the same time, the Zn content was correlated with the percentage of compost in the nutrient substrate mixture (Figure 2 d). The highest Zn content in plants was registered in V20 (100% HHC) - 75.2 mg kg^{-1}d.m., V14 (75% C3_OFSMV) - 70.5 mg kg^{-1}d.m., V5 (75% PMFWC) - 58.7 mg kg^{-1}d.m. and V15 (50% C3_OFSMV) - 57.0 mg kg^{-1}d.m. In a study regarding different composts obtained from the biodegradable organic fraction of their municipal solid waste, Paradelo et al. (2020) highlight contents in ryegrass plants of 103 and 133 mg kg^{-1}d.m., while the reference values range between 25 and 47 mg kg^{-1}d.m. (Kabata-Pendias & Pendias, 1984). Other authors mention an average-normal Zn content in plants, ranging between 20 and 150 mg kg^{-1}d.m. (Jones, 1972).

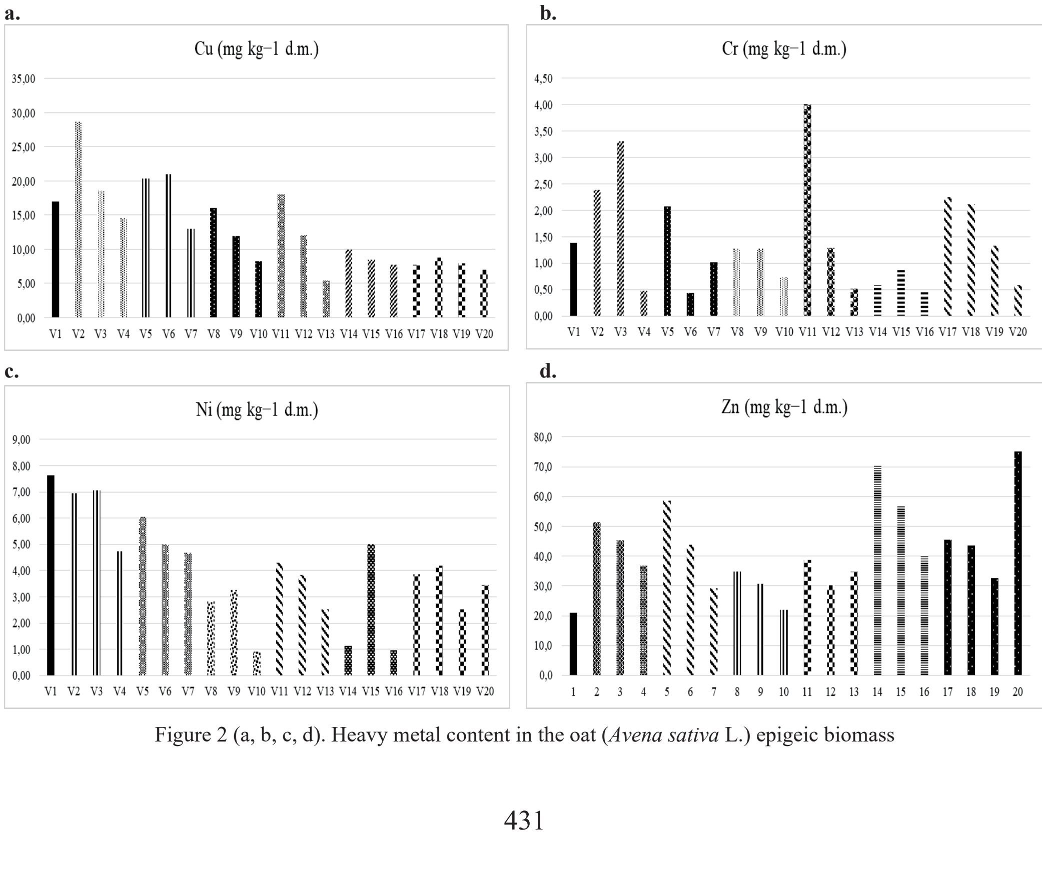

Figure 2 (a, b, c, d). Heavy metal content in the oat (*Avena sativa* L.) epigeic biomass

Physico-chemical characteristics of soil and compost mixtures after harvesting oat plants. The C_org. content in soil and compost mixtures (Figure 3) increased in all variants compared to the control, regardless of the proportion of composts in the mixture. However, the most relevant contents were registered, in general, in the variants in which the proportion of composts was of 75% and 50%. Also, the composts contributed to increasing the pH value (Figure 4) of soil and compost mixtures so that, in most variants, the pH had values that indicate a neutral to weak-alkaline reaction (Blaga et al., 2008).

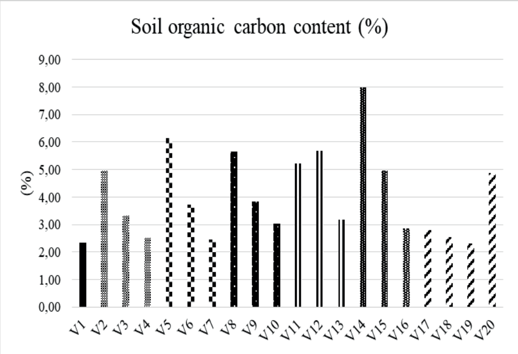

Figure 3. Organic carbon content in soil and compost mixtures after harvesting oat biomass

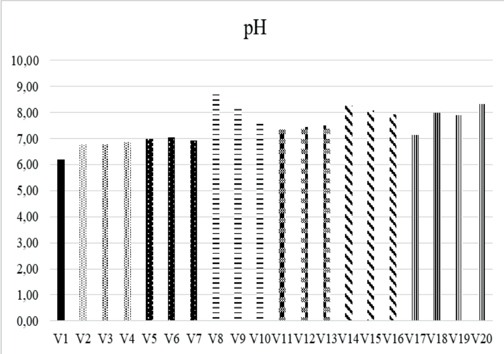

Figure 4. pH values of oil and compost mixtures after harvesting oat biomass

The macronutrients (N, P and K) content in soil and compost mixtures was, in most variants, above that of the control variant and, in general, it increased simultaneously with the proportion of composts in the soil and compost mixtures (Figure 5). However, N content was registered below the level of the control variant (V1 - 0.31% N) in almost all the variants in which the composts were in a proportion of 25% g/g in the composition of the mixtures. The P content was above the control variant level (V1: 0.23% P) except for the V19 variant (0.19% P). The K content was also above the level of the control variant (V1: 1.30% K) in most variants except V2 (1.15% K) and variant V19 (1.25% K). The highest K content was registered in the composts obtained from OFMSW followed by HHC, PMFWC and PMWSC.

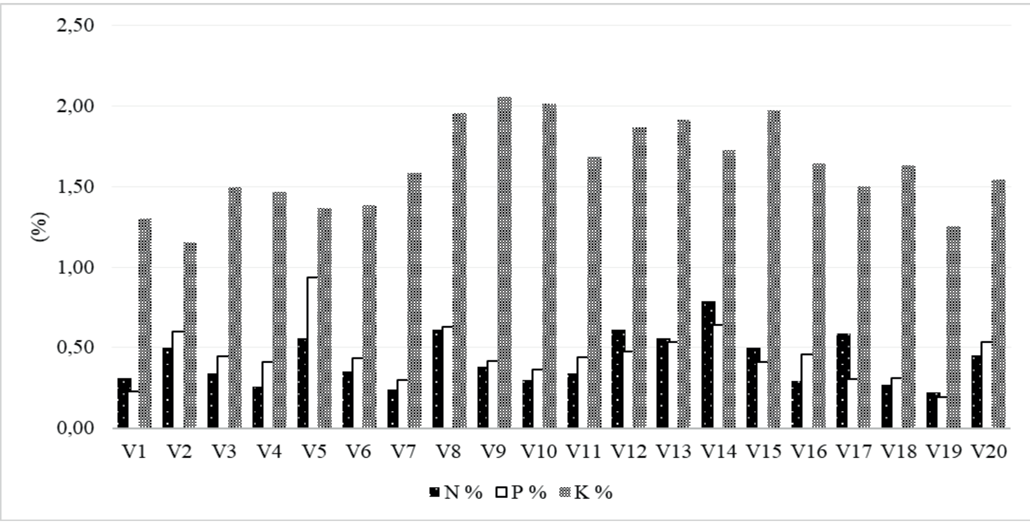

Figure 5. Macronutrients (N, P, K) in soil and compost mixtures after harvesting oat biomass

Heavy metal content in soil and compost mixtures after harvesting oat plants.

The Cu content (Figure 6 a) in soil and compost mixtures was influenced by the proportion of the compost in each variant and exceeded the content of the control variant, but it was below the limit of 100 mg kg^{-1}d.m. accepted by Romanian legislation (ORDER no. 344/2004).

The compost that had the highest intake was C3_OFSMW in a proportion of 75% in the mixture.

The Cr content (Figure 6 b) was also above the level of the control variant in all variants in which composts were used in mixtures. The Cr content did not necessarily correlate with the level of compost intake. The order of magnitude of the Cr content depending on the type of compost in the mixture was as follows: C3_OFSMW>C2_OFSMW>HHC> C1_OFSMW>PMFWC>PMWSC.

The Cr content in soil and compost mixtures was below the limit imposed by the Romanian legislation (100 mg kg^{-1} d.m.). The Ni content in soil and compost mixtures (Figure 6 c) was below the level registered in the control variant and also below the limit imposed by Romanian legislation (50 mg kg^{-1} d.m.). The Zn content (Figure 6 d) in soil and compost mixtures after harvesting the oat plants was above the level registered in the control variant and, in most variants, below the limit imposed by the Romanian legislation (300 mg kg^{-1} d.m.). However, in two of the variants, contents over Romanian limits were highlighted (389 mg kg^{-1}d.m. in V20 – 100% HHC and 412 mg kg^{-1} d.m. in V14 – 75% C3_OFSMW.

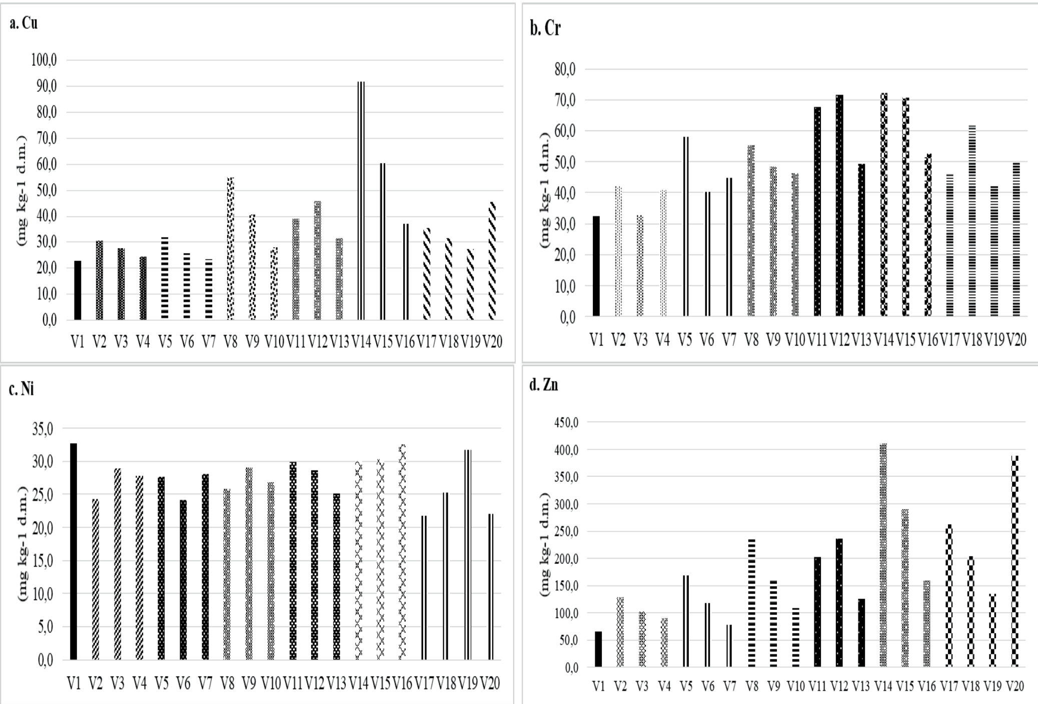

Figure 6 (a, b, c, d). Heavy metal content in soil and compost mixtures after harvesting oat plants

Table 3. The maximum admissible values for heavy metal concentrations in soils where sludge is applied (mg/kg of dry matter in a representative soil sample with pH > 6.5) according to Romanian legislation (ORDER no. 344 from August 16, 2004)

	Cd (mg kg^{-1}d.m.)	Cu (mg kg^{-1}d.m.)	Ni (mg kg^{-1}d.m.)	Pb (mg kg^{-1}d.m.)	Zn (mg kg^{-1}d.m.)	Hg (mg kg^{-1}d.m.)	Cr (mg kg^{-1}d.m.)
Romanian legislation (ORDER no. 344/2004)	3	100	50	50	300	1	100

CONCLUSIONS

The source-separated collection of bio-waste at is essential for the development of a composting chain integrated into the circular economy. This allows a good control of the raw materials for composting, a good management of the composting parameters and the composting process, as well as obtaining a good quality compost.

For the rural environment in Romania, given the conditions generated by the current energy crisis, but especially to reduce the waste management costs of rural communities, to contribute to reducing the impact of organic waste on the environment and to produce useful and good quality organic amendments to improve soil physico-chemical properties and its fertility, source-separated collection and home composting of bio-waste can be a sustainable solution.

For the agricultural use of composts resulting from bio-waste, the doses to be used must be established according to the intake of nutrients, especially N and according to their heavy metal content.

The composts tested in the study have an important agronomic value considering the biomass production achieved in all experimental variants. However, the highest productions were registered for composts obtained from bio-waste collected separately at the source, and the most relevant soil and compost mixture could be 50% soil + 50% compost for potted crops, also in correlation with the chemical composition of compost (macro- and micronutrients and heavy metals).

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