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Co-composting of Sewage Sludge, Green Waste, and Food Waste

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ABSTRACT

Rapid population growth requires more intense production of food industry, with two major consequences: significant amount of food processing residues and more sewage sludge originating from biological wastewater treatment plant. Sludge is a big concern for the disposal for wastewater treatment plant. The European Union makes an effort regarding the reduction of organic fractions disposed at a landfill. Composting is a cost-effective and ecological-friendly alternative for managing biodegradable organic fractions. Experiments of co-composting of sewage sludge, green waste and food waste, at carbon/nitrogen ratios 8.75, 18.00 and 24.90, were performed during three months by monitoring temperature, pH, moisture, carbon and nitrogen proportion, carbon/nitrogen ratio, and germination index. The results showed that co-composting of sewage sludge, green waste, and food waste is effective and results in the production of quality compost.

KEYWORDS

Co-composting, Sewage sludge, Green waste, Food waste, Carbon/Nitrogen, Waste reduction.

INTRODUCTION

Garden and food waste contribute approximately 30–40% of total municipal waste in the European Union [1]. Municipal solid waste contains a high proportion of organic materials, from 50% to 65% [2]. Since 1999 member states of the European Union have been urged to decrease the quantity of biodegradable waste at the landfill [3] and encouraged to sort waste at the origin, recycle, and recovery [4] to meet the goals for recycling and renewable energies [1]. A vast problem worldwide is the disposal of wastewater treatment sludge [5] because of the increasing amount and continuous production [6]. Sludge might be an alternative source of soil organic matter [7]. However, sewage sludge should be stabilized and sanitized before application on agricultural soil.

Composting, a low-cost and simple way for managing organic waste [8], is a technique of biological waste transformation by naturally occurring microorganisms in the presence of oxygen and under thermophilic conditions [9]. Composting is characterized by the decomposition and stabilization of organic matter. Compost, the final product, is stable without pathogens [10] and can be used for agriculture land amendment [1].

Substrate characteristics, such as nutrient composition, size of the particles, ratio C/N (carbon to nitrogen), and process conditions, such as aeration, moisture content, temperature, and pH, affect the composting process. C/N ratio in the range from 25 to 30 is generally recognized as optimal [11], as well as 25–35 [12]. However, some authors suggest the C/N ratio of 15 [13], higher than 18 [14], and 20 [15] is sufficient for effective composting.

Co-composting (composting two or more organic waste materials) was the subject of numerous studies. These included: co-composting of green waste and food waste, raked leaves and grass clippings at C/N ratios 13.9–19.6 [11], yard waste and food waste at ratios 70%:30%, 80%:20%, 90%:10%, and 100% yard waste [16], kitchen waste and different bulking agents (cornstalks, sawdust, and spent mushroom substrate) [17]; food waste, green waste and sewage sludge in different proportion: sewage sludge (20–40%), green waste (40–50%) and food waste (10–40%) at C/N ratios 20.9-24.7 [6], sewage sludge (30–86%), green waste (14–35%) and food waste (0–55%) at C/N ratios 11.61–19.87 [18]; wastewater treatment sludge with different bulking agents, such as freshly collected yard trimmings originating from a city collection, yard trimmings of similar origin but stored for three weeks in static piles, crushed wood pallets and deciduous tree bark [5], straw and sawdust [19], crushed wood pallet, pine bark and corn stalk [20], wheat straw, plane leaf, corncob and sunflower stalk [21], and maize straw [22].

The composting of sewage sludge is quite a challenge due to the low C/N ratio, high-density structure, and it must be free of pathogens before use as fertilizer [19]. The characteristics of sewage sludge and urban untreated waste are opposite: low C/N ratio, dense structure, and high moisture vs. high C/N ratio and low density. Therefore, bulking agents (such as green waste – adsorbent) are an advantageous option for soaking up the moisture of the sewage sludge. The inclusion of bulking agents into composting substrate [5] boosts the aeration rate [20], especially in natural, non-mechanical aeration systems. It increases the composted material porosity, proven in the study of wastewater treatment sludge composting and different bulking agents [21] and with maize straw as bulking agent [22].

The aims of this research of co-composting of sewage sludge, green waste, and food waste were:

- estimating the possible mixing of green waste, sewage sludge, and food waste for efficient co-composting, especially at low C/N;
- assessing the impact of different initial C/N ratios on the effectiveness of the co-composting process, based on physical/chemical properties of waste; and
- evaluation of produced composts for use in agriculture.

MATERIALS AND METHODS

The set-up of the experiments of the co-composting process, the characteristics of composting mixtures, and analytical methods are described below.

Composting process

The composting mixtures used in the co-composting experiments are shown in **Table 1**. The mixtures included:
(i) unprocessed food waste (FW) collected from households,
(ii) green waste (GW) from municipal biodegradable waste (branches, leaves, wood waste from gardens and parks), and
(iii) stabilized sewage sludge (SS) from wastewater treatment plant (WWTP) Koprivnica, Croatia (**Table 2** and **Table 3**).

The household food waste was chopped up manually, and the green waste was chopped up with a shredder for branches to approximately 5 cm to accelerate stabilization [23]. Experiments were performed as static piles with manual turning.

The proportion of heavy metals in the sludge was below the concentrations permitted for WWTP sludge which is supposed to be used in agriculture in Croatia [24]. The final compost was not analysed for heavy metal content based on determining heavy metals in the sludge.

Table 1. Characteristics of the composting mixtures SS+GW, SS+GW+FW and SS+FW

	Mixture SS+GW	Mixture SS+GW+FW	Mixture SS+FW
Waste	SS/GW	SS/GW/FW	SS/FW
Ratio	30:70 v/v	30:50:20 v/v	70:30 w/w
pH	7.05	7.20	6.47
Temperature [^{o}C]	22.00	25.20	20.40
Moisture [%]	50.80	59.25	54.50
Organic C [%] (dry weight)	39.45	36.26	24.40
Total nitrogen [%] (dry weight)	1.58	2.01	2.79
C/N ratio	24.90	18.00	8.75

Table 2. Physico-chemical composition of aerobic stabilized sludge (mean ± standard deviation, n=3)

Parameter	Value
pH (10% eluate)	7.62±0.13
[%] H_2O	68.00±3.00
[%] ash (550 °C) (dry weight)	56.00±2.00
[%] volatile solids (dry weight)	44.00±2.00
[%] organic C (dry weight)	24.46±0.54
[%] N (wet basis)	0.589±0.091
[%] N (dry weight)	1.87±0.04
[%] NH_3-N	0.36±0.01
[%] P_2O_5 (dry weight)	1.45±0.07
[%] K_2O (dry weight)	1.79±0.06
[%] Ca (dry weight)	3.81±0.04
[%] Mg (dry weight)	0.78±0.03

Table 3. Microelements and heavy metals in aerobic stabilized sludge (mean ± standard deviation, n=3)

Parameter	mg kg^{-1} (dry weight)
Fe	1590±23
Mn	490±7
Zn	130±8
Cu	40.0±0.5
Ni	17.2±0.9
Cr	13.4±0.4
Hg	0.0821±0.012
Cd	1.182±0.1
Pb	24.7±0.9

Many researchers have analysed the toxicity of heavy metals [25] and the migration of heavy metals in soil fertilized with sewage sludge [26]. In most European countries, including Croatia [24] and many other countries, the heavy metal content in sludge used for agricultural purposes is limited [25]. The total concentration of heavy metals in sewage sludge cannot provide useful information about the risk of bioavailability, toxicity, and the capacity for immobilization in the environment. The mobility and bioavailability of heavy metals in soil fertilized with compost may change over time. During the composting of organic matter, humus substances can chelate heavy metals and reduce the bioavailability of these metals in the final product. The total content of metals in sewage sludge depends primarily on the source of wastewater (municipal, industrial) and their composition and less on the treatment of sewage sludge [27]. The results of sludge analysis indicate that the sludge has valuable plant nutritional properties, with a high amount of Ca, Fe, and Mn, and can be used in agriculture. The sludge nutrient content, microelements, and heavy metals were determined at the University of Zagreb, Faculty of Agriculture. A moisture check was done by the FIST test [28]. The composting piles were manually turned once a week during the first month of composting, afterward once a month.

Analytical methods

The eluent was prepared according to Huang *et al*. [13] and used for analysis. The compost pH was measured in deionized water extract (1:10 w/v) by WTWMulti 3420 SET KS1, Germany. The moisture content was measured by drying the material at 105 °C per 24 h, and the ash content was determined by ignition at 550 °C per 5 h. Total nitrogen was determined by the Kjeldahl method. Analysis of P_2O_5, K_2O, Ca, and Mg was determined by atomic absorption spectroscopy (AAS). Heavy metals analysis was performed after acid digestion by AAS.

The 48-h germination assay was used to test the toxicity to plants [29]. An aqueous extract was prepared to determine the seed germination index (GI). The test was conducted in the dark at 20±1 °C. A filter paper previously moistened with 8 mL of compost extract was placed in a 10 cm diameter Petri dish, with evenly placed ten cucumber seeds. As a control, deionized water was used. For each compost, three replicates were incubated. The GI was determined according to formula (1):

$$GI\ [\%] = \frac{(treatment\ seed\ germination\ [\%] \times treatment\ root\ length) \times 100}{control\ seed\ germination\ [\%] \times control\ root\ length} \quad (1)$$

RESULTS AND DISCUSSION

Sewage sludge is rich in organic matter, contains nitrogen, phosphorus, potassium, and other nutrient elements, and might be used as a cheap source of organic substrate for aerobic composting. Sewage sludge has a high content of organic matter and a rich microbial community, which can decompose organic matter and effectively solve the acidification problem caused by food waste during the composting process. Co-composting can effectively shorten the entire composting cycle and improve the compost maturity and its fertilizer quality [30]. Co-composting of sludge and other organic waste was proven more effective than separate composting of waste. It enhances many microbially mediated biogeochemical processes and lowers the loss of nutrients during composting [18]. Sewage sludge compost significantly improved the chemical and physical properties, such as nitrogen content, porosity, moisture, organic matter content, and respiration, of the reclaimed soil in a landfill [31]. The sludge has a low C/N ratio, high moisture content, and thick structure [32]. Green waste as bulking agents provides free air space and fibrous carbonaceous material and balances the water contents of composting mixture by modifying the properties of waste during composting such as low C/N ratio, high moisture, and high density [33]. Food waste contains a significant amount of easily degradable organic matter [11] and is characterised by a low C/N ratio, high moisture, high concentration of nitrogen, and low pH value [14]. Food waste conversion efficiency and stability are relatively low since the organic portion of food waste is unstable and readily acidified [34]. Fruit waste is readily degraded to organic acids with high quantities of leachate; therefore, mixing fruit waste with green waste (bulking agent) is highly recommended to obtain adequate moisture content for composting [35].

Variations of pH, temperature, and moisture content in the composting piles during the three months of composting are shown in Figure 1. The variations of pH were the most intense in the mixture SS+GW. The acidification was observed with the lowest pH 5.27 recorded in the first month of composting. The composting in mixture SS+FW was performed under slightly acidic conditions, with pH in the range of 6.47–6.85. The final composts SS+GW, SS+GW+FW, and SS+FW, obtained pH of 7.20, 7.14, and 6.58, respectively (**Table 1**, **Figure 1**), which is in the range of pH 6–8 for the mature compost [8]. During the composting of the mixture SS+GW+FW, no acidification was recorded. One can reduce acidification during the food waste composting by mixing food waste and sludge since sludge contains high organics concentration and numerous microbes capable of organics decomposition [30]. In the early stage of composting, the acidic pH in composting mixtures results from organic degradation by acid-forming bacteria [35]. As the composting process continues, the ammonia is released due to ammonification and mineralization of organic nitrogen, and pH becomes alkaline. In the final phase of composting, pH is around neutral due to the formation of humus [9].

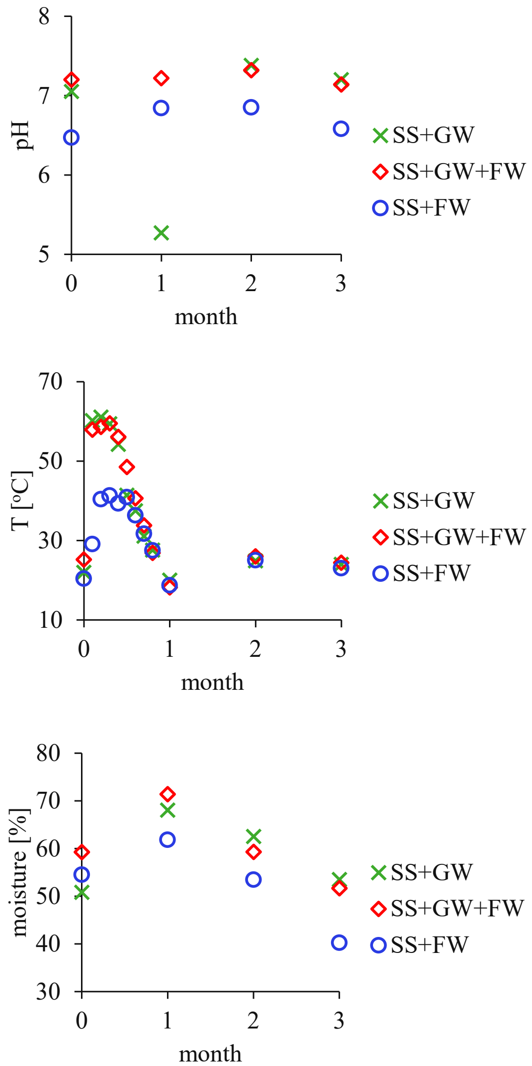

Figure 1 Variations of pH, temperature and moisture content in composting piles SS+GW, SS+GW+FW and SS+FW during 3 months

The temperature changes during the composting in composting mixtures SS+GW and SS+GW+FW exhibited a similar trend, with a slightly higher recorded temperature during the composting of the mixture SS+GW. In comparison, in the mixture SS+FW, the temperature was lower. So, in this study, composting mixtures composition and moisture content affected the temperature behaviour. Temperature increases were recorded in the first week in all piles. In composting piles SS+GW and SS+GW+FW, the observed temperature was above 55 °C, while in composting pile SS+FW, the highest temperature was around 40 °C. After the initial increase, a decrease in temperature was observed in all piles (**Table 1**, **Figure 1**). It was pointed out in the study **[30]** on co-composting of excess sludge and food waste (1:1, 2:1, and 4:1) that the higher proportion of sludge, the higher the temperature, and vice-versa, the highest temperatures recorded were 54.9 ºC, 59.7 ºC and 58.4 ºC in reactors containing 1:1, 2:1, and 4:1 sludge to food waste, respectively. Also, in the study **[18]**, it is suggested that the higher the C/N ratio, the higher temperature during the composting process. The same suggestion is in the study **[19]**, which agrees with the results obtained in this study (**Table 1**, **Figure 1**). The temperature transformations during the composting process can be identified as mesophilic stage, thermophilic stage, cooling, and maturation **[36]**. In the first mesophilic stage, the temperature increases due to the rapid mesophilic microorganisms' activity and colonization. The degradation of organics and heat release increases the temperature of the composting mixture. The heat speeds up the subsequent microorganisms' metabolism rate and intensifies the decomposition of organics present in the composting mixture and the heat production. In the second thermophilic stage, the temperature rises fast due to the high activity of microorganisms indicating high degradation rates of the mesophilic stage **[37]**. Then, in the third stage, the temperature decreases significantly due to the lower activity of the microorganisms caused by the depletion of easily degradable organics **[38]**. The microflora diversity during the aerobic composting of biowaste (fruit and garden waste, vegetables) was investigated **[39]**. As the composting process reached the thermophilic phase, the number of microorganisms declined and raised as the temperature decreased. An enzyme activity assay, the indicator of overall microbial activity, exhibited the decline of microbial activity during the thermophilic phase, then the increase, and eventually decline in the maturation phase. The thermophilic phase was characterized by the predominance of bacteria (bacilli), with a negligible amount of yeasts, streptomycetes, and fungi. As the thermophilic phase approached the end, the variety of bacteria increased.

In this study, the measured temperature was suitable for microorganism growth, and in composting piles SS+GW and SS+GW+FW, high enough for elimination of viable weed seeds and pathogens (hygienisation) **[40]**. For adequate hygienisation, all composting material should be exposed to over 55 °C for at least 4 h **[41]**. Another study reported that after 96 days of home composting of leftovers of raw fruits and vegetables at average temperature 37.4 °C (variations between 20–65 °C), the produced compost was hygienised **[40]** due to natural decay of pathogens since the residence time of waste in a home composting is relatively long **[42]**. Although during the composting process in this research, the thermophilic temperature range in composting pile SS+FW was not reached. As the composting was performed for three months, the natural decay of pathogens may have occurred. The low C/N ratio of 8.75 in composting mixture SS+FW was the reason why the thermophilic conditions were not reached **[11]**. In experiments of co-composting of sewage sludge, straw, and sawdust at C/N ratios 9.2, 12.1, 17.0, and 26.4, it was highlighted that the ratio C/N significantly affects the composting temperature, in such a way that the higher C/N ratio, the higher the temperature and composting rate **[19]**. Furthermore, in co-composting experiments with green waste and food waste at different C/N ratios and moisture content, at C/N ratio of 14.5 and moisture content 70.61% and 49.35%, the highest recorded temperature was 35 ºC and 69.4 ºC, respectively **[11]**. It was pointed out that under high moisture content, oxygen transfer limited the activity of the microorganisms, which resulted in a slow temperature increase during the composting. Also, the microbial activity is directly affected by moisture content, and therefore, so are temperature and decomposition rate. In contrast, it was pointed out that moisture content did not significantly affect the compost quality [29] in experiments with pig feces and cornstalks at moisture content 65%, 70%, and 75%. Furthermore, it was highlighted that the temperature during the composting process is a case-specific parameter that does not explicitly depend on the composition of composting mixtures; it may also depend on other parameters [43].

The observed changes of moisture exhibited the same trend in all composting mixtures. The moisture variations showed the trend of the increase of moisture in the first month, and in the following months the moisture was decreasing. The final composts had the lower moisture content in composting mixtures SS+GW+FW and SS+FW. The moisture content loss was 7.62% and 14.31% in produced composts SS+GW+FW and SS+FW, respectively (**Figure 1**). It is believed the moisture content should vary 50–60% [2]. In some food waste, such as vegetable waste, the moisture content can be more than 85% [18]. In this research, the moisture content varied depending on the composition of composting mixtures. The lower moisture content of 50.80% was recorded at the composting mixture SS+GW since this mixture was composed of sludge and green waste, a bulking agent [5] that reduces the moisture content [44]. The sludge is often composted with bulking agents to reduce the thickness of sludge and its water content. Another benefit of adding bulking agents to sludge is to provide aerobic conditions during composting [5]. The composting mixture SS+FW recorded the lowest moisture content in final compost, 40.19%. The final composts SS+GW and SS+GW+FW achieved similar moisture content, 53.47% and 51.63%. The present results (**Table 1**, **Figure 1**) agree with the study [6], in which moisture content in the range 37.8–47.3% was obtained for final composts made of composting mixtures of sewage sludge, green waste, and food waste. The results also agree with the study [30] in which moisture content was in the range 50.73–56.21% in co-composting of sludge and food waste.

The comparison of carbon and nitrogen proportion and C/N ratio in initial composting mixture piles with the final compost is shown in **Figure 2**.

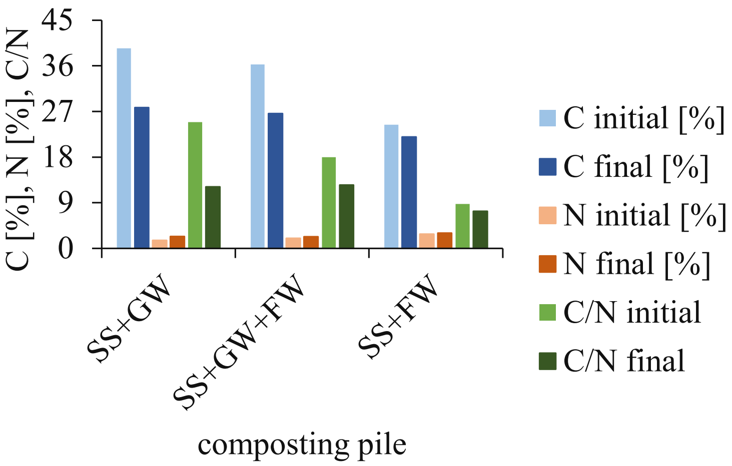

Figure 2. Carbon and nitrogen proportion and C/N ratio in initial composting piles and in compost in examined mixtures SS+GW, SS+GW+FW, and SS+FW

The carbon proportion in initial composting mixtures was as follows: mixture SS+FW (24.40%) < SS+GW+FW (36.26%) < SS+GW (39.45%). Despite different starting points, the final composts SS+GW, SS+GW+FW, and SS+FW obtained similar carbon proportions: 27.78%, 26.60%, and 21.96%, respectively, with recorded carbon loss of 11.67%, 9.66%, and 2.44%, respectively, expressed as the difference between initial and final value. The mass balance after three months of composting showed carbon loss of 29.58%, 26.64%, and 10.00%, respectively, expressed as the ratio of initial carbon (**Figure 2**). During the composting, carbon transfer can happen among various organic fractions [45].

In the mixtures SS+GW+FW and SS+FW, due to the addition of green vegetables (food waste, see **Table 1**), the nitrogen concentration was higher than in the mixture SS+GW. Final composts SS+GW, SS+GW+FW and SS+FW in this research had 2.35%, 2.29% and 3.00% ratio of nitrogen, respectively, which is within values for good quality compost (0.4–3.5%) **[46]**. The nitrogen ratio in composts is an indicator of large fertilizing capacity and small loss of nitrogen due to ammonia emissions during composting **[40]**. These emissions result from the conversion of unstable ammonia to stable, organic forms of nitrogen **[47]**. The removal of NH_4-N from the compost is a result of nitrification. The nitrifying bacteria convert NH_4-N over nitrite to nitrate **[48]**. The final composts SS+GW, SS+GW+FW, and SS+FW recorded a minor increase of nitrogen ratio, 0.77%, 0.28%, and 0.21%, expressed as the difference between initial and final value. The mass balance after 3 months of composting showed nitrogen increase of 48.73%, 13.93%, and 7.53%, respectively, expressed as the ratio of initial nitrogen (**Table 1**, **Figure 2**). The nitrogen loss occurs due to the volatilisation during the composting process **[49]**. The reduced emissions of CO_2 and NH_3 are related to a smaller loss of nitrogen, and a greater amount of nitrogen **[50]** and organic carbon **[51]** in the final compost, which benefits the compost quality **[52]**. An increase in nitrogen content in composting mixtures SS+GW, SS+GW+FW, and SS+FW can be explained by the biodegradation of organics. These decreased from 39.45% to 27.78% in mixture SS+GW, from 36.26% to 26.60% in mixture SS+GW+FW, and from 24.40% to 21.96% in mixture SS+FW, **Figure 2**. The same was observed in the study **[21]**. In the composting process, the nitrogen concentration increased due to the decomposition of the labile organics **[53]**.

Initial C/N ratio of 25–30 is considered optimal for the aerobic composting process **[11]**, as well as 25-35 **[12]**. However, the ratio C/N 15 **[13]**, higher than 18 **[14]**, and 20 **[15]** are also reported to be adequate for effective composting. The initial C/N ratios in composting mixtures increased in following order: SS+FW (8.75) < SS+GW+FW (18.00) < SS+GW (24.90), see **Figure 2**. Other authors also pointed out that the higher proportion of green waste, the higher is the ratio C/N **[18]**, which agrees with the present study results. The challenge in this research was composting process at a low C/N ratio (composting mixtures SS+GW+FW and SS+FW), and only the initial composting mixture SS+GW was set as recommended in the literature, in the range 25–30 **[11]** or 25–35 **[12]**. It was suggested that the initial C/N ratio for sludge and bulking agents composting mixtures should be as high as possible to achieve nitrogen conservation during composting and raise the availability of nitrogen in the final product **[5]**. Since bulking agents take part in carbon and nitrogen evolution, they affect the characteristics of the final product and its agronomic value **[20]**. As pointed out in another study on co-composting sludge (20–40%), green waste (40–50%), and food waste (10–40%), with an accent to optimal moisture content and C/N ratio **[6]**, a greater contribution of sludge might decrease the C/N ratio, which is in agreement with our results.

The C/N ratios of final composts SS+GW and SS+GW+FW were quite similar, 12.12 and 12.49, respectively, while the C/N ratio of final compost SS+FW was the lowest, 7.30 (**Table 1**, **Figure 2**). Regardless of different compositions of initial composting mixtures and especially at low initial C/N ratio (8.75 and 18.00), all composts reached the C/N ratio as recommended in the literature (**Figure 2**), around C/N 10 **[54]** or C/N 15 or lower **[4]**, as an indicator of compost maturity. During the composting, organics are transformed to carbon dioxide, and with the slightest N loss, the ratio of C/N inevitably decreases **[55]**. The C/N ratio decreased in final composts SS+GW (51.3%), SS+GW+FW (30.6%), and SS+FW (16.6%), as shown in **Figure 2**. The decline of the C/N ratio indicates mineralization during the composting **[33]**. Even though the composting process emits more than 100 groups of gaseous compounds, composting can be recognized as an environmentally friendly solution **[56]**. Of the total emission, 99% is made of CO_2, volatile organic compounds, NH_3, CH_4, and N_2O, and the emitted CO_2 – not derived from fossil – is not regarded as a greenhouse gas emission **[57]**. The composting mixtures and the process parameters affect the amount and quality of emitted gases and are substantially variable **[58]**. Sewage sludge composting and recycling can be an environment-friendly solution to disposal problems and an economic strategy for improving the soil conditions in landfills [31]. Due to the remarkable benefits in terms of valuable product production, reduction of waste – disposal of sludge, green and food waste, composting is considered an eco-friendly process [58].

The compost is recognized as mature and phytotoxic-free if the GI is higher than 80% [59]. **Table 4** shows it was achieved in this research.

Table 4. Germination index of composts SS+GW, SS+GW+FW and SS+FW

Compost	Germination index [%]
SS+GW	85
SS+GW+FW	83
SS+FW	89

The compost containing 2.6% nitrogen, 27% carbon, 0.9% phosphorus and 2% potassium can be considered as "high quality" compost [60]. It was obtained for all mixtures, as indicated by a slightly more intense smell and dark-brown to black colour. The compost consistency was more balanced in the interior of the piles. The undecomposed woody material at the pile surface made it necessary to sieve the final compost.

The efficient recovery and reuse of sewage sludge, green waste, and food waste is an environmentally safe and cost-effective solution of waste management [61]. The benefits of compost application in agricultural soils are maintaining or restoring the quality of soils, thus reducing the need for inorganic fertilisers, with a net contribution to the end-of-waste policy in Europe [62].

CONCLUSIONS

The co-composting of sewage sludge, green waste, and food waste even at a low C/N ratio of 8.75, 18.00, and 24.90 resulted in high-quality composts. The research results can contribute to the restoration and conservation of soil fertility, expand carbon storage capability, and decrease synthetic fertilisers use. All produced composts are appropriate for agriculture use; however, since the compost of sewage sludge and food waste obtained the highest germination index (89%), it would be the most appropriate one.

Resource recovery from sewage sludge and other organic waste has become the new focus of waste and wastewater management to develop sustainable processes in a circular economy approach. The composting of sewage sludge and other organic waste (green and food waste) brings benefits like cost reduction and compost environmental effects as organic soil amendments to increase soil organic matter content. It is a vital strategy to comply with the Landfill Directive and the end-of-waste policy in Europe.

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NOMENCLATURE

Abbreviations

WWTP	Wastewater Treatment Plant
SS	Sewage Sludge
FW	Food Waste
GW	Green Waste
GI	Germination Index
AAS	Atomic Absorption Spectroscopy

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