

Chapter

Increasing the Value of Waste Hop Biomass by Composting: Closing the Nutrient Cycle on Hop Farms

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Abstract

After the harvest of each hectare of hop (*Humulus lupulus* L.), an average of 15 tons of fresh waste plant biomass, consisting of leaves and stems, is generated next to the harvest hall. On-site (on-farm) composting is an excellent way to manage excess biomass after the harvest, and it can help to establish a circular economy in the hop-growing sector. It is essential that the resulting compost is both nutrient-rich and safe for use, while also avoiding any potentially harmful leachate impacts. We have to establish the compost pile as soon as possible after the harvest, and to mix it several times during the thermophilic phase, related to temperatures measurements. After approximately 2 months, the pile will begin to cool down, at which point it is advisable to cover it with a semi-permeable membrane. Five months later, the compost is mature—ready to use as an organic fertilizer with app. 9.6 kg N, 1.6 kg P, and 5.9 kg K per ton, no phytotoxic properties, stable, and suitable for plant production (based on the radish germination index of GI 89%). The cress germination test (average of GI 196%) has demonstrated that it is a nutrient-rich and stimulating substrate.

Keywords: *Humulus lupulus* L., composting, compost fauna, nutrients content, circular economy, germination test, circular economy, resource efficiency

1. Introduction

The hop plant, *H. lupulus* L., is cultivated for its cones, which are an essential ingredient in the brewing industry. During the harvest, the plants are cut, and the aboveground biomass is removed from the fields to the harvesting machine, which harvests the hop cones; they are collected, dried, and packed for use in the brewing industry. The stems and leaves are left in this procedure as a by-product next to the harvest machine (see **Figure 1**), with the supporting twine intertwined within this waste material. In a single growing season, the hop plant can attain a height of up to 7 meters and as a climbing plant requires a guiding twine for support. Typically, plastic twines or iron strings in conjunction with plastic twine are utilized and, to a lesser



Figure 1.

Subsequent to the harvest of the hop cones, waste hop biomass in the form of hop stems and leaves is generated as a by-product and accumulates in close proximity to the harvest machine hall (photo: L. Luskar).

extent, also biodegradable twine made from renewable sources like jute, coconut husks, or polylactic acid.

Every harvest season, the hop industry generates on average 15 tons of waste hop biomass (fresh matter) from each harvested hectare of hop fields [1]. So 2600 hop farms with 26,500 hop fields in the European Union produce beside 50,000 tons of hop cones per year [2] also 400,000 tons of waste hop biomass, which is of good composition for on-site (on-farm) composting [1], although this use is not common. However, based on massive amounts of organic waste produced on hop farms, on-site composting of hop biomass needs to be considered because it offers a perfect way for nutrients and organic matter to be returned to the agricultural fields in the narrowest circle possible.

Hop biomass after harvest contains roughly 18% organic mass, 0.8% nitrogen, 0.3% potassium, and 0.1% phosphorus, with a carbon-to-nitrogen ratio of 13:1 [1]. The ratio between carbon and nitrogen in waste hop biomass is 13:1 when composting stems and leaves together and 23:1 when composting only stems [1].

Composting represents a conventional, low-investment technology for transforming biomass into a stabilized end product with low levels of readily degradable organic matter and without any phytotoxic effects on plants [3, 4]. This approach aligns with the need to develop new methods for reducing the use of chemical fertilizers [5, 6]. Hop biomass can be taken to industrial composting plants, where it is mixed with other organic materials and subjected to thermal and technical processing, after which it is sifted to produce high-quality and safe compost. Alternatively, on-site composting (i.e., on-farm composting) represents a much more cost-effective option for farmers, which, if properly managed, can be just as efficient as industrial composting.

2. Hop biomass on-site (on-farm) composting

Utilization of biodegradable twine as a plant support mechanism in hop fields during the growing season serves as a favorable predisposition for the appropriate composting of hop biomass. Before harvesting, the knife on the harvest machine has to be checked, sharpened, and set for cutting the stems into pieces smaller than 5 cm. During the harvest, the knife has to be cleaned several times per day. Before composting, the location of the placed compost pile has to be determined in line with national rules and regulations.

The compost pile has to be set right after harvest or no later than two days after harvest. Biomass could be collected on a tractor trailer and transported directly to the location of composting. Otherwise, the collecting biomass place could be right next to the harvesting hall, later loaded on the trailer, and taken to the location of composting. The optimal direction of compost pile placement is north-south.

The quantity of fresh waste hop biomass from a one-hectare hop field ranges between 13 to 20 tons, depending on variables such as the hop variety, agricultural practices, and weather conditions during the growing season, with an average of approximately 15 tons [7]. This quantity of biomass is sufficient to establish favorable conditions for successful composting.

The LIFE BioTHOP project has introduced a 100% biodegradable and 100% on-site compostable bio-plastic polylactic acid (PLA) twine, which offers improved solutions for managing hop biomass, including its use as a substrate for producing high-quality compost. When subjected to proper on-site composting, this twine is broken down into CO₂, water, and organic matter. To optimize composting characteristics, the stems of hop plants should be cut into pieces that are less than 5 cm in length (**Figure 2**). However, if plastic supporting twine is still being used by hop growers, the stems on the harvest machine should be cut into longer pieces, not shorter than 30 cm, so they can be fully sifted out by the sieving machine. This ensures that the final compost is completely free of plastic particles.

For optimal composting, it is recommended to shape the hop biomass pile into a trapezoidal form, with a height of approximately 3 meters and a maximum settled height of 1.5 meters. The slope of the pile should be even to prevent waterlogging and should be constructed in a manner that allows for proper drainage of precipitation, without being absorbed into the pile. The actual size of the pile may vary depending on the method of mixing, and hop growers may adjust the shape and size of the pile over time to accommodate their experience and mixing techniques.

Regular temperature measurements must be taken within the hop biomass pile. The initial mixing of the pile should be performed once the temperature has surpassed 60°C for three consecutive days or when a temperature of 65°C has been recorded for two consecutive days. The pile must be turned to ensure that previously exposed parts are mixed inside the pile. During the thermophilic phase, when the temperature exceeds 45°C, it is recommended to turn the pile at least once per week. If the temperature rises above 60°C, the pile should be turned twice per week. After each mixing, the pile should be re-shaped into a trapezoidal form [7].

Ensuring an appropriate temperature distribution within composting piles is a critical aspect of achieving effective composting and preventing pathogen contamination. Generally, the temperature in the core of the pile is higher than the outer layer (as shown in **Figure 3**). In our experiments, we observed a temperature difference of roughly 10°C between a depth of 30 cm and 1 m. The outer layer, which is approximately 30 cm thick, did not exceed 55°C in our trials. Neglecting to adequately sanitize this outer layer can lead to the proliferation of phytopathogens, which can spread to the rest



Figure 2.

It is recommended that hop stems be cut into smaller pieces during the harvesting process if biodegradable and compostable twine is present (photo: L. Luskar).

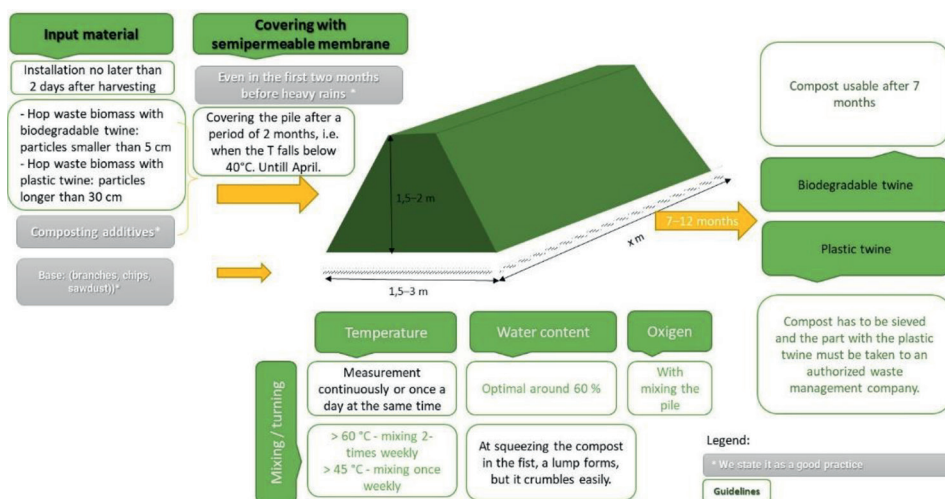


Figure 3.

A diagram of on-farm hop biomass composting (L. Luskar).

of the pile and the field soil if the compost is used there. Regularly turning the pile is essential for ensuring uniform composting and proper heat distribution throughout the biomass. Furthermore, closely monitoring temperature and moisture levels can help maintain optimal composting conditions and minimize the risk of pathogen contamination. Ultimately, effective management of composting piles is crucial for preventing the spread of plant diseases and promoting sustainable agriculture practices.

Composting leaves together with stems can increase the overall efficiency of the process. The addition of leaves can improve nutrient availability within the compost and prevent excessive drying caused by empty spaces within the pile. This extended thermophilic phase resulting from the inclusion of leaves is critical for both the degradation of PLA twine and the hygienization of the biomass. Therefore, composting the entire biomass after harvest is recommended to optimize the composting process. Two key factors for efficient composting are the combination of small biomass particles and frequent turning of the pile. The small particle size provides a larger surface area for microbial activity, leading to faster decomposition and composting. Frequent turning of the pile facilitates proper oxygen flow and moisture distribution, which are necessary for the growth of microorganisms and the prevention of odors and pathogen growth [8].

Overall, composting the entire biomass after harvest can provide greater benefits for soil fertility and sustainability. With the appropriate management practices in place, such as maintaining the appropriate moisture and oxygen levels and regularly turning the pile, the composting process can be optimized to achieve maximum efficiency and nutrient content. A diagram of on-farm hop biomass composting is presented in (Figure 4).

During the stabilization phase of composting, the temperature of the pile typically drops below 40°C. In hop biomass composting, this starts after around 2 months from the start, that is, in November. To optimize the composting process and prevent nutrients loss, it is advisable to keep the pile covered with a semi-permeable membrane during this phase (Figure 5). This helps to retain heat and moisture within the pile, prevent leaching,

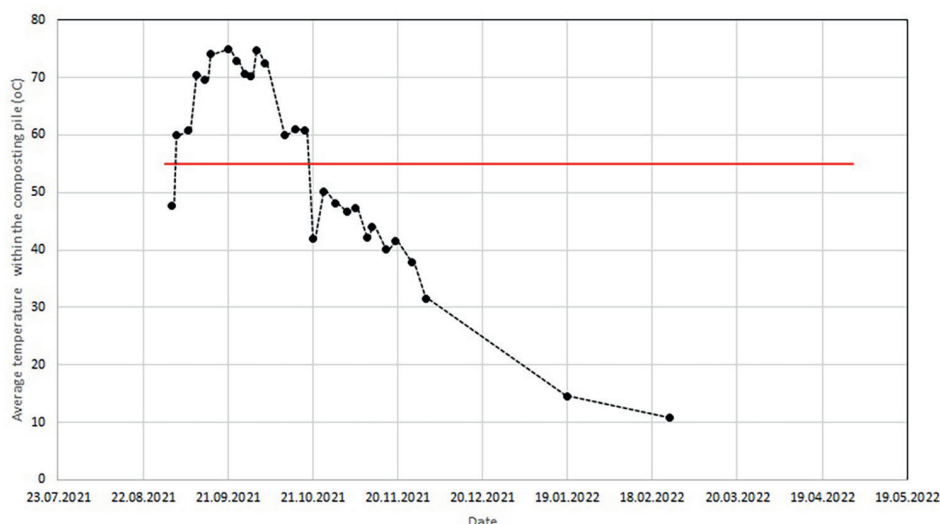


Figure 4.
 Temperature in composting hop biomass pile with proper mixing procedure and time – An example.



Figure 5.
Composting hop biomass in winter, covered with a semipermeable membrane.

and facilitates optimal microbial activity. Once the compost has stabilized and the temperature has decreased to a level comparable to its surroundings, it can be considered for use. The core of the pile should have the same temperature as the surroundings and should exhibit a soil-like odor. Considering our experiments, this is in about seven months after the start of proper composting, in April of the following year.

3. Hop biomass compost characteristics

The characterization of hop biomass compost is typically determined using a range of chemical tests, including pH tests and assessments of ammoniacal nitrogen, organic C, total N, nitrate nitrogen, potassium, and phosphorus levels. In addition, water content is an important characteristic of compost that is commonly measured. Due to variations in input materials, such as differences in hop stem length and various additives that can be added at the start, including biochar and effective microorganisms, there may be differences in the chemical composition of hop biomass composts. Nevertheless, average values of key characteristics are presented in **Table 1**, along with a comparison to the original starting/fresh material. Final compost (dw) contains about 3–4% nitrogen, 0.3–0.4% phosphorus, 1.0–2.5% potassium, and 35–43% total organic carbon [8].

Legend: dry matter (DM), total nitrogen (TN), total phosphours (TP), total potassium (TK), total carbon (TC), nitrate nitrogen ($\text{NO}_3\text{-N}$), ammoniacal nitrogen ($\text{NH}_4\text{-N}$).

The pH range of mature compost is a crucial factor in determining its suitability for use in agricultural applications. According to Hachicha et al. [9] and Rynk et al. [10], the optimal pH range for mature compost is between 6.0 and 8.5. The pH of the hop biomass mature compost falls within this range at 7.8, while the pH of the hop biomass input material is around 6.5. Similar increase in pH has been observed in horticultural waste composting, as reported by Choy et al. [11]. Despite these general trends, it is important to note that the pH requirements of specific plants may vary [12].

	Start	End
pH	6.5	7.8** – 8.4*
DM (%)	27.8	31.2** – 31.3*
TP (%) ¹	0.28	0.38** – 0.46*
TK (%) ¹	1.67	1.08** – 2.07*
TC (%) ¹	48.1	22.8** – 34*
TN (%) ¹	2.6	2.7** – 3.5*
NO ₃ -N (mg/kg) ²	0.8	376** – 1051*
NH ₄ -N (mg/kg) ²	170	83* – 404**

Legend: dry matter (DM), total nitrogen (TN), total phosphorus (TP), total potassium (TK), total carbon (TC), nitrate nitrogen (NO₃-N), ammoniacal nitrogen (NH₄-N).

¹Measured in dry matter.

²Measured in fresh matter.

*Following the thermophilic phase lasting approximately two months, composting piles were covered with a semipermeable membrane for an additional five months (unpublished data of Institute of hop research and Brewing).

**Composting piles uncovered [8].

Table 1.

The basic chemical characteristics of both the input material (fresh hop biomass after harvest) and the final/mature compost produced after seven months of on-site composting.

The dry matter (DM) content of hop biomass compost typically undergoes a slight increase during the composting process, rising from an initial level of 27.8% to approximately 31.2% [8]. For mature compost to be effective in agricultural applications, it should have a DM content falling within the range of 30–50%, according to McFarland [13].

During the composting process, the average total nitrogen (TN) content of compost piles typically increases. Research has shown that biochar can be particularly effective in reducing nitrogen losses from composting materials, according to Steiner et al. [14]. In general, composts with a total nitrogen content greater than 2% are suitable for use as fertilizer, so compost from hop biomass covers this requirement [8].

The average phosphorus content (TP) of fresh hop biomass after harvest is typically around 0.28% in dry matter. During the composting process, it increases to around 0.38% in dry matter. Conversely, the average potassium content (TK) in hop biomass typically decreases during composting [8].

The expected range of potassium content in compost is typically reported to be between 0.6 and 1.7% [15]. The final hop compost pile analyzed in our study met this standard with a potassium content of 1.1% [8]. Adebayo et al. [16] reported a decrease in total potassium content during composting of food waste and yard trimmings, except in a closed system, where it initially increased before falling below the initial value in the substrate mixture. The total carbon (TC) content decreased significantly from an average of 48–23% of dry mass during composting, which is expected due to microbial immobilization of approximately 40% of available carbon, with the remaining 60% lost through respiration [17].

The average nitrate content (NO₃-N) in fresh hop biomass was found to be around 0.8 mg/kg and 375.9 mg/kg in the final compost [8]. This is consistent with nitrate being the final product of nitrogen mineralization [18] and an expected increase during composting. The starting material had an average ammoniacal nitrogen content (NH₄-N) of 169.6 mg/kg, while the final composts had 403.8 mg/kg [8]. Contrary to the expected decrease in ammonia levels during the maturation phase [19], our findings suggest an increase. Piles with added biochar had the highest nitrate and

ammoniacal nitrogen content, indicating their potential to prevent nitrogen losses during composting [14, 20, 21]. The findings suggest that additives and small particle sizes contribute to nutrient retention in the pile; however, the most important factor is covering the pile with a semipermeable membrane throughout the maturation phase.

Compost stability and maturity are the main properties to characterize compost quality [22, 23]. However, chemical characterization alone is not enough to assess compost maturity. The phytotoxic effect on plants is related to immature compost, while low microbial respiration indicates compost stability [22, 23]. Germination and growth tests [24] are used to determine the effect of compost on plants. The method combines seed germination index and root elongation of cress seeds and garden radish (*Lepidium sativum* L. and *Raphanus sativus*) [25]. The number of germinated seeds is counted, and the overall length of seedlings (root) is evaluated. The number of germinated seeds and the length of the radicle are both affected by the compost extract, while the germination index (GI) describes both parameters compared to the control.

In 7 months, all the hop waste biomass composts had reached the mature phase. None of the composts from hop biomass in our research were phytotoxic ($GI < 65$) according to the Zucconi [25] criteria based on the germination index. The BioTHOP PLA twine inside has loosened its strength and was degraded. The degradation level was correlated with the level of shredding and differed due to the presence or absence of leaves. Taking the radish germination index (average of GI was 89%) into consideration, the composts in our study showed a substrate with no phytotoxic properties, stable and appropriate for plant production, whereas in the cress germination test, the composts showed nutrient-rich or stimulating substrates. The germination index was between 125 and 213 (average of GI 196%), and microbial respiration was between 0.1 and 0.2 C-CO₂/g compost/day [8].

When properly composted, hop waste biomass composts had an earthy smell with no phytotoxic effect on plant germination. The most promising treatment for on-site composting after the first year of trials is indicating to be good shredding (pieces smaller than 3 cm) and proper aeration/mixing in the thermophilic phase of the process. Previously considered agro-waste can now be used as an organic fertilizer, when properly on-site (on-farm) composted.

4. Hop biomass compost microbiological properties

Microorganisms are ubiquitous in the environment and play a pivotal role in the biochemical degradation of organic matter. These microbes are responsible for converting nutrients from organic to plant-available mineralized forms [26]. A single square centimeter of the plant leaf surface is typically colonized by approximately 10^6 – 10^7 bacteria [27], making plant material a significant source of microbial activity. Additionally, the soil serves as a reservoir for biological degraders, and when composting is carried out on soil, the microbes can enter the compost pile during the process.

The composting process is influenced by several factors, including the composition of the feedstock, moisture levels, oxygen content, pH, and temperature. As such, a comprehensive understanding of the microbiological processes at work is essential to supplement compost chemical composition analysis [28]. Soil compost amendments contribute to the general soil quality recovery and improvement of plant growing conditions by providing numerous ecosystem services, including replenishment of soil carbon stocks, increase of microbial activity and biodiversity, and restoration of plant nutrition [29]. Compost is normally populated by 3 general categories of

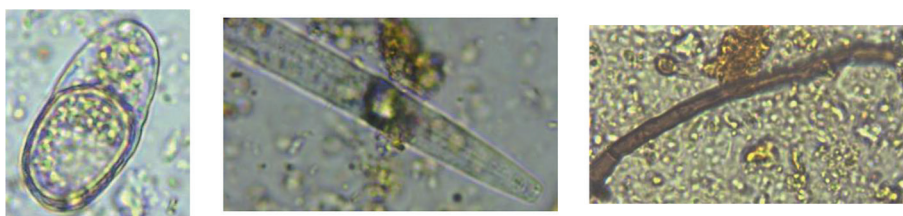


Figure 6.
Amoeba, nematode, and aerobic fungus, detected in mature hop biomass compost (photo: J. Kadunc).

microorganisms: bacteria, fungi, and actinomycetes. It is primarily the bacteria, and specifically the thermophilic bacteria, that create the heat of the compost pile [30].

During the composting process, the conditions in the pile, including temperature, aeration, moisture, pH, and substrate availability, are subject to constant change, resulting in stages of microbial consortia and their fluctuation [31]. The initial decomposers are mesophilic organisms such as bacteria and fungi. In the subsequent stage, thermophilic organisms, particularly actinomycetes, become dominant, and fungal populations decline. During the maturation phase of composting, a new mesophilic community develops, with actinomycetes remaining and fungi reappearing, along with cellulose-decomposing bacteria [32].

Only a sample study has been performed by now since the beginning of our research on the on-site hop biomass composting some years ago, to take the snapshot of hop biomass composts microbiological properties (**Figure 6**), in which we found out that the microbial world of composted hop biomass was dominated by bacteria [33]. Part of fungi mycelium was also found, but in general, diversity, which is main property of quality compost, was not high. The observed count of colonies forming units was approximately 10^6 CFU per gram of dry matter, falling within the anticipated range [34]. Fast-changing conditions in soil (heat, drought, moisture, and lightness) demand fast adaptation of microbes that can only be tackled by diversity. Due to their fast reproduction, the number does not play such an important role as their diversity. The work on the topic will continue within our research group on the composts from improved composting procedures [33].

5. Fauna in hop biomass compost

While processes of nutrient cycling are governed directly by microbes, such as bacteria and fungi, they are also affected by soil animals that live alongside them. Soil fauna affects decomposition processes both directly, through fragmentation and comminution of litter material, and indirectly, by altering microbial function through grazing of the soil microbial biomass and through excretion of nutrient-rich wastes. The movement of animals through soil influences the dispersal of microbial propagules attached to the animal body surfaces or transiting through their guts [35]. Invertebrates co-exist with the microbes and are essential to a healthy compost pile.

The mesofauna and macrofauna are a diverse group of organisms, varying in size from tiny mites to large insects, that inhabit the composting biomass under investigation. These organisms play a crucial role in decomposing the organic material and providing nutrients for the entire food web, which restores the natural balance in the compost. Obtaining rich, mature compost with a healthy population of fauna is essential because these organisms help to maintain the physical and chemical properties of

the compost through their mechanical and chemical actions. By breaking down the organic material, they facilitate the nutrient cycling process, which is crucial for the growth of healthy plants. Therefore, it is crucial to ensure that the composting process allows for the growth and proliferation of these important organisms.

The fauna in the composting piles after five months from the start of the composting process (in winter) was dominated by springtails, mites, spiders, centipedes, soldier fly, and larva. The most numerous in all compost piles were springtails (at least ten in 2 g of compost) and mites (at least ten in 2 g of compost). A wide variety of arthropods were found in the compost pile, where effective microorganisms were mixed in at the start of composting. In the mature compost, in April, the most numerous were springtails, which were of various sizes and colors, and mites. Amoebas, earthworms, centipedes, spiders, larva, beetles, and insects were also detected (**Figure 7**).

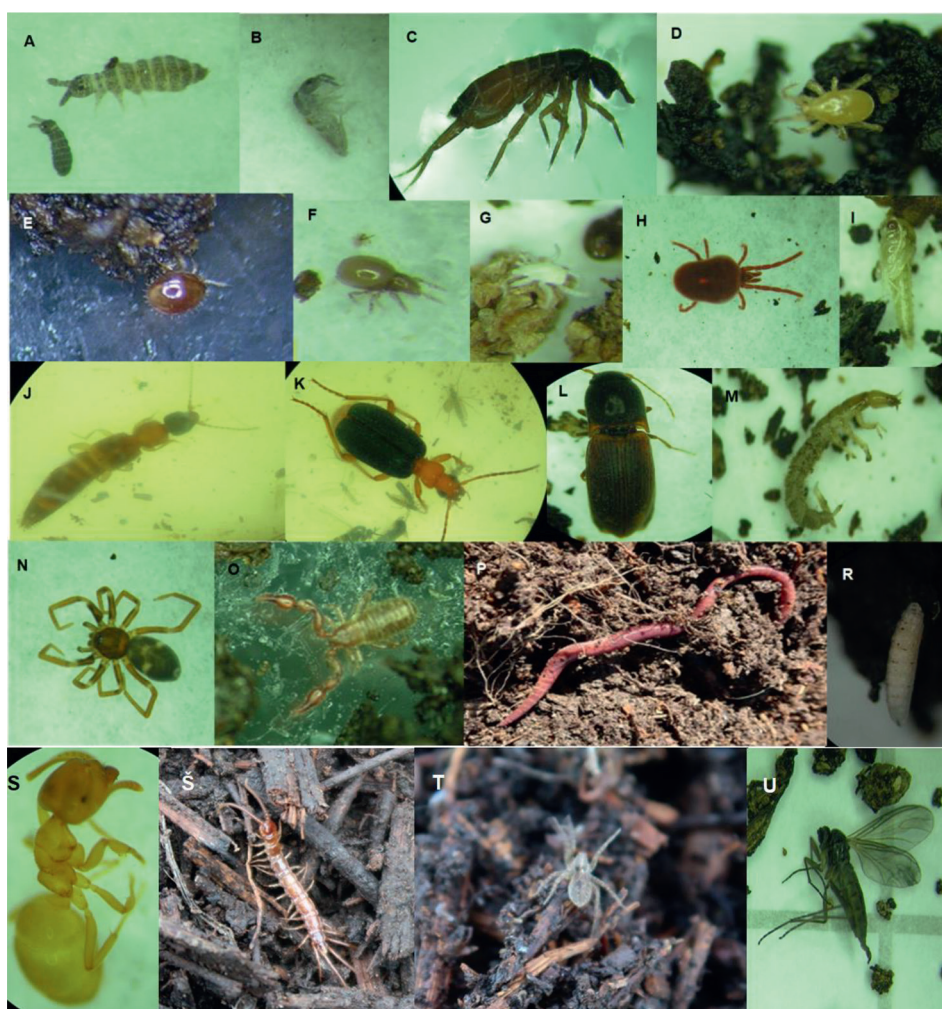


Figure 7. Fauna detected in hop biomass compost (photo: A. Karničnik Klančnik). A, B, C –springtails Collembola; D, E, F, G, H – Mites (Acarina); I – The initial stage in the development of an insect; J, K, L – beetles (Coleoptera); N, T – Spiders (Araneae); O – Pseudoscorpions; P – Earthworm; R – Larva; S – Ant; M, Š – Centipedes; T, U – Soldier Fly.

6. How to use hop biomass compost and why

To avoid the phytotoxic impact, which can delay seed germination or inhibit plant growth, compost should be mature and stable before being used as a fertilizer [36].

A ton of compost from hop biomass with an average moisture content of 70% contains 8.1 kg of total nitrogen (N), 1.14 kg of total phosphorus (P) or 2.6 kg of P_2O_5 , and 3.24 kg of total potassium (K) or 3.8 kg of K_2O , according to current IHPS measurements [7]. If the compost pile is covered over the winter to be protected from leaching of the nutrients because of higher precipitation, the compost contains more nutrients. A ton of compost with an average moisture content of 70% contains 9.6 kg of total nitrogen (N), 1.56 kg of total phosphorus (P) or 3.57 kg of P_2O_5 , and 5.93 kg of total potassium (K) or 7.15 kg of K_2O . A comparison with nutrients content in farmyard manure is presented in **Table 2**. However, it is advised to analyze each compost for the water content and main nutrients content in order to obtain accurate information before its use. By taking into account the soil analysis and nutrient removal from the soil with the certain crop, we can more accurately calculate how much compost can be used to fertilize a certain crop. We adhere to a five-year fertilization plan because in this way, we ensure the gradual achievement and maintenance of a good soil supply with nutrients and maintain soil fertility.

Compost can serve as an effective fertilizer, much like stable manure. The percentage of organic mass (over 35%) indicates that the compost is within the criteria of the first-class compost. Hop growers can load mature compost on the spreader and spread it across the field without problems. It can be utilized for basic fertilization in the spring or fall, by incorporating it into the soil. For example, it can be incorporated during basic tillage before sowing maize, which is an ideal timing as mature hop compost is typically available in April. Compost is also suitable for use in fertilizing hop fields, grasslands, at planting vegetables, and sowing cereals. However, in cases, where the hop biomass used in the composting process is infected with hop wilt, as a precautionary measure, we recommend that the compost is not returned to the hop fields but rather utilized in other fields or grasslands.

If we take into account the limitation of the annual nitrogen fertilization, which amounts to 250 kg/ha N with organic fertilizers, we can therefore apply a maximum of 30 t/ha of such compost in one year if the compost would be the only fertilizer. The limit of 250 kg/ha N applies to all types of organic fertilizers together, that is, for livestock fertilizers and all other types of organic fertilizers (digestate, compost, etc.) together [38]. So if we use any other organic fertilizer, then we must accordingly

Nutrient	Hop biomass compost with 70% moisture (kg/t)	Stable manure (kg/t) with 81.4% moisture*
N	8.1** - 9.6***	4.7
P_2O_5	2.6** - 3.6***	3.0
K_2O	3.9** - 7.2***	5.1

*The average moisture of hop biomass compost after 7 months was found around 70% according to IHPS measurements. Stable manure's average moisture is 81.4% [37].

**Uncovered composting piles [8].

***Following the thermophilic phase lasting approximately 2 months, composting piles were covered with a semipermeable membrane for an additional five months (unpublished data of the Institute of hop research and Brewing).

Table 2.
Comparison of nutrients content in hop biomass mature compost and farmyard manure.

reduce the amount of compost. When deciding on the dose of fertilizer for an individual crop or vegetable, it is also necessary to take into account the limit values of the total intake of nitrogen with fertilizers (organic and mineral fertilizers) for individual types of agricultural plants per individual unit of agricultural land use in accordance with the plants' nitrogen needs and measures to reduce and prevent water pollution. In any case, it is recommended to have a fertilization plan, which must include a calculation of nitrogen fertilization needs, based on expected yield.

Regarding the use of compost, it is necessary to adhere to the decree on the protection of waters against pollution caused by nitrates from agricultural sources, guidelines for the implementation of water protection requirements against nitrate pollution from agricultural sources, keep an eye for proper application technique, timing, and cross-compliance.

To present a positive impact of mature hop biomass compost use for fertilization compared to fresh hop biomass incorporation, a pot experiment was set with Chinese cabbage (*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt). Treatments were: K (control), 185 g substrate; SH (fresh hop biomass), 27 g fresh hop biomass +148 g substrate; and ZK (mature compost), 27 g mature compost +148 g substrate. In 4 days, there were significantly fewer plants emerged in SH compared to ZK and K, but later there were no significant differences between the treatments in the number of emerged plants. The above-ground biomass of the plants after 47 days, when the experiment was evaluated, was statistically significantly the most abundant in ZK, whose leaves were the most intensely green at the same time (**Figure 8**). There was no significant difference in biomass weight between K and SH, but the leaves of K were of paler green color. The content of nitrate in the leaves was significantly higher in ZK (130 mg/L) compared to K and SH (19 mg/L and 36 mg/L, respectively). The content of nitrate in the substrate was significantly higher in SH (<3.8 mg/L) compared to ZK and K (<3 mg/L). The content of ammonium nitrogen was significantly lower in K (0.3 mg/L) compared to SH and ZK (0.7 mg/L). The density and branching of the root system were the highest in ZK and the worst in SH (**Figure 9**).



Figure 8.

Fertilization pot trial with Chinese cabbage (*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt) after 47 days from sowing; left: Fresh hop biomass (SK) mixed in substrate at sowing, middle: Mature hop biomass compost (ZK) mixed in substrate, right: Control (K) with pure substrate.

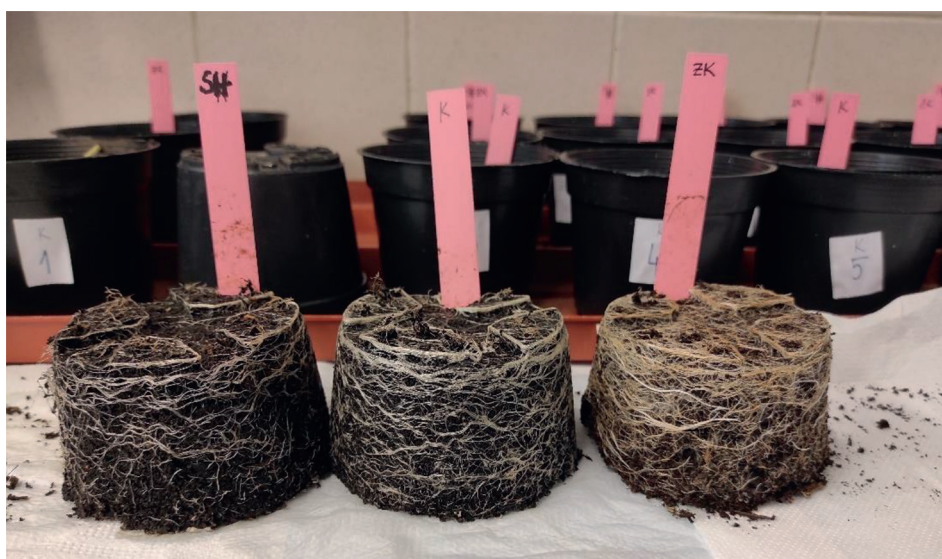


Figure 9. Roots check in fertilization pot trial with Chinese cabbage (*Brassica rapa* L. subsp. *chinensis* (L.) Hanelt) after 47 days from sowing; left: Fresh hop biomass (SH) mixed in substrate at sowing, middle: Control (K) with pure substrate, right: Mature hop biomass compost (ZK) mixed in substrate.

7. Conclusions

Following the harvest of every hectare of hop (*Humulus lupulus* L.), an average of 15 tons of fresh waste plant biomass, consisting of leaves and stems, is generated next to the harvest hall [1]. This green waste is mostly seen as a waste and represents additional disposal cost to the farmers but can also be transformed into compost through on-site composting, which is a sustainable and effective means of repurposing this waste product [8]. To ensure a high-quality compost product with minimal environmental impact throughout the on-site composting process, advanced composting technology has been developed. This technology offers one of the most promising means for returning essential nutrients and organic matter to the agricultural land of the same farm. By recycling this waste product in this manner, farmers can enhance soil fertility and maintain the health and productivity of their crops while also minimizing the environmental footprint of their agricultural operations [39].

Adhering to professional composting guidelines is essential to ensure that the resulting compost is both nutrient-rich and safe for use while also avoiding any potentially harmful leachate impacts. One critical consideration in this regard is the amount of precipitation, as there is a strong linear correlation between this factor and the volume of leachate produced [40]. To minimize the risk of leachate-related issues, it is vital to implement appropriate measures. One of the most effective strategies is to cover the composting pile with a semipermeable membrane, particularly after the end of the thermophilic phase, which typically occurs approximately two months after the start of the process. This covering should remain in place throughout the maturation phase, which extends until April of the following year. By following these guidelines, farmers and composting operators can minimize leachate impacts, avoid the loss of nutrients, and therefore produce a high-quality, nutrient-rich compost product [7].

With on-site hop biomass composting, farmer gets his own organic fertilizer, which can be applied safely to his agricultural land, and in this way, the cycle of the nutrients and organic matter returned back to the agricultural land is the narrowest possible. The compost, prepared according to the professional guidelines is safe, contains nutrients, organic matter, many microorganisms, such as bacteria, actinomycetes, and fungi, as well as different fauna species, which enhance soil biodiversity when applied to the agricultural land.

With a bit of effort to guide a proper process of composting, farmer can save some money on the purchase of fertilizers and avoids landfill costs. And the last but not the least, a circular economy on farm is established.

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