Characterization of Compost from Reusable Industrial Streams:

Physical, Nutrient, and Microbial Properties

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Department of Biosystems and Technology
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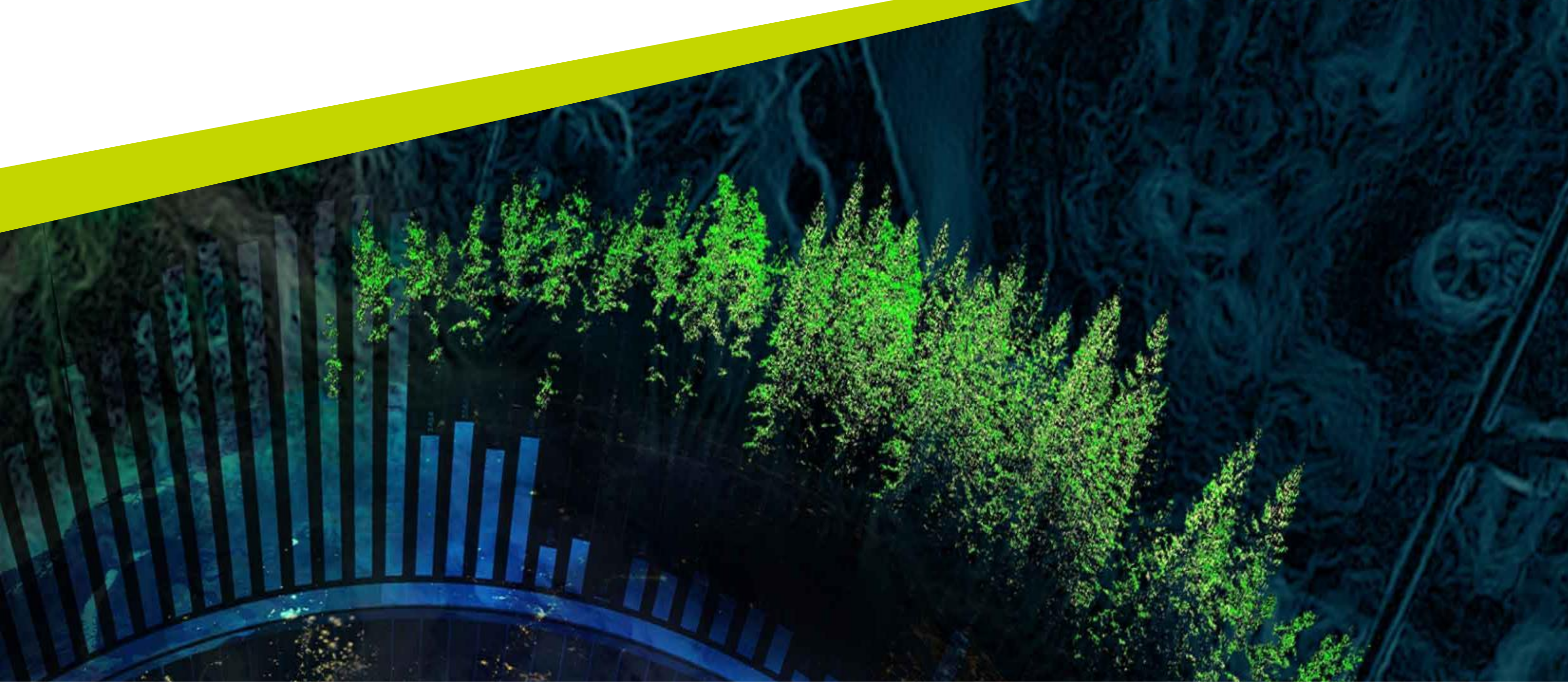

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Abstract

The increasing global population, combined with soil degradation, poses challenges to food security, and raises concerns about the excessive and long-term use of conventional fertilizers. Evaluating sustainable alternative by-products for their soil-improving properties could offer a potential solution, particularly for Swedish fruit producers who can tap into local waste streams as a circular source of plant nutrients. The main objective of this study is to investigate the quality of a one-year-old compost derived from different ratios of spent mushroom compost (SMC), apple waste and wood chips. As these materials originate from waste streams of agricultural practices, three different compositions were used to assess the individual impacts of the materials on quality. A series of tests were conducted to measure the physical properties, chemical content, and microbial growth to determine the current status of the compost, and its suitability as a fertilizer in fruit production. The study found that no significant difference in physical and microbial quality could be observed, leading to the conclusion that the characteristics of the composted materials had been partly neutralized as an effect of decomposition rates. This suggests that the ratios of the mixed materials did not have a substantial effect on overall compost quality. However, the results of pH and EC measurements showed that the combination of SMC, apple waste and wood chips potentially could stabilize the high salinity levels of SMC after one year. Another finding revealed that there were significant differences in nitrogen concentration, particularly in the treatment with the highest proportions of SMC. This specific treatment demonstrated higher nitrification rates compared to the others. This study aims to lay the groundwork for investigating alternative by-products as potential sources of fertilizer. Further research is required to explore the soil amending qualities of the compost when used as a growing medium, and its effects on apple cultivation. By conducting additional studies in this area, a more thorough understanding of the compost's potential as a growth medium and its impact on apple crops can be obtained.

Key words: Spent mushroom compost, apple orchard waste, soil amendment, compost, optimization, circular agriculture

Contents

Abbreviations

SMC	Spent mushroom compost
OM	Organic matter
EC	Electrical conductivity
WHC	Water holding capacity
COD	Chemical oxygen demand
TSA	Tryptic soy agar
KB	King’s B agar
MA	Malt extract agar
VRBD	Violet red bile dextrose agar
CFU	Colony forming units
PGPR	Plant growth promoting rhizobacteria

1. Introduction

1.1 Background

With today's continuously growing population together with the degradation of agricultural soils, there is an ongoing problem with decreasing food security. At the same time there is concern about the lack of soil management along with a high-prized market questioning the excessive and long-term use of conventional fertilizers. One way to mitigate these concerns is to evaluate sustainable alternative by-products and their soil improving properties to create a circular exchange of plant bound nutrition. For a growing number of fruit producers in Sweden, the solution could be found locally, in their own streams of waste.

Among the varied growing conditions for Swedish fruit producers, sandy soils often lack organic matter followed by nutrient depletion and a declined soil quality (Swedish Board of Agriculture, 2021). The use of synthetic fertilizers worsens the issue, leading to changes in soil structure, contamination of underground waters, and accumulation of heavy metals in agriculture (Vahid Afagh et al., 2019). Fertilizers made from various types of organic waste have lots of benefits and has a great economic and environmental advantage in comparison to non-renewable resources like peat or mineral fertilizers (Jakubus, 2020).

Today's plenitude of organic waste is closely related to the intensification of agricultural systems and has for long been the subject in the evolvement of biorefinery (Azim et al., 2017; Qin et al., 2021). One way to manage this surplus is by composting, turning waste into resources. The main idea of composting derives from the decomposition of organic waste components and raw materials through natural biological processes under aerobic conditions (Azim et al., 2017). This means that there is a vast range of diversity of microorganisms, along with a chemical and biological variety, depending on the materials being composted.

1.1.1 Spent mushroom compost (SMC)

An alternative source of organic matter is the reuse of SMC, which stands for spent mushroom compost. Spent mushroom compost is a by-product of mushroom cultivation made up of the remaining substrate after mushroom harvest. It is mostly associated with *Agaricus bisporus* (champignon or button mushroom) that needs to grow in a composted substrate (Uzun, 2004). The substrate typically consists of a mixture of materials including agricultural waste products such as straw, hay, and seed hulls, as well as animal manure, gypsum, and other supplements (Uzun, 2004). These materials are combined, pasteurized to kill any pathogens, or weed seeds, and then inoculated with mushroom spawn. After the mushrooms have been harvested, the remaining substrate is considered "spent" because the nutrients and energy required for mushroom growth have been depleted. However, the remaining substrate still contains a significant amount of organic matter, mostly lignocellulosic, which can be broken down further to release additional nutrients (Paredes et al., 2009). The present results demonstrate the great potential of using SMC as a soil amendment or fertilizer to improve soil health (Uzun, 2004; Paredes et al., 2009; Vahid Afagh et al., 2019). Its positive effects on soil structure have shown great improvements when it comes to water-holding capacity. Oppositely, SMC also has high salinity levels due to the presence of calcium, sodium, potassium, nitrate, and ammonium ions, which can lead to problems when too much SMC is added to the soil or when plants are grown directly in SMC (Uzun, 2004). Leaching of SMC during the composting process can also stabilize the materials and induce maturity, as observed in some studies (Uzun, 2004). To avoid raising soil conductivity levels, it is recommended to mix SMC with other media before use, as suggested by Gonani et al. (2011) and Uzun (2004). Finding a suitable media to combine with SMC can have a positive impact on the circular economy, and the slow-released nutrients in SMC can have a long-term beneficial use in fruit orchards (Uzun, 2004).

1.1.2 Apple orchard waste as biorefinery

As a part of the search for biomass-based alternatives, waste from apple orchards has been studied for its beneficial qualities. According to a study by Guardia et al. (2019), apple processing industries produce 20 million tons of waste per year worldwide. This abundance of organic material, along with its physiochemical properties, makes apple waste a suitable resource for bio-refinery development (Qin et al., 2021; Caldeira et al., 2020). Apple waste is generated through both agricultural activities and post-harvest processes, and all organic materials are used in the form of by-products. This waste includes discarded plant material, such as leaves and branches, as well as spoiled apples from growth, picking, storage, and transportation, thus involves all stages of the source material (Qin et al., 2021).

However, using untreated apple waste as fertilizer has its limitations and a direct environmental impact. The raw materials contain a high content of slow and fast degrading fibres, including lignin, cellulose, and hemicellulose, as well as soluble substances such as pectins, β-glucans, and non-digestible oligosaccharides (Calderia et al., 2020). The degradation of these substances involves continuous fermentation and has a high chemical oxygen demand (COD). While a high COD indicates, in the case of apple waste, the large amounts of organic matter it can contribute to water pollution and produce emission gasses when released into the environment (Guardia et al., 2019).

Also considered a waste product, wood chips are readily available as a source of organic material on a farm scale level. When added to a compost mixture, its slow degrading fibrous structure helps improve stability with the gradual release of carbon, increase of aeration and porosity thus maintaining the optimal conditions for microbial activity. Overall, the inclusion of wood chips as a bulk agent can enhance the physical characteristics of the compost and decomposition process (Vandecasteele et al., 2004; Agnew and Leonard, 2003).

This investigation is part of a larger ongoing project with the main objective of establishing a foundation for studying the quality of compost particularly made from a combination of spent mushroom compost, apple waste and wood chips. The exploration of the beneficial qualities in source materials from reusable industrial waste streams can contribute to the development of alternative growing media (Taparia et al., 2021). Good soil amending qualities in compost is dependent on the specific needs of the soil. Generally, compost with a high content of organic matter is desirable as it can improve soil structure and provide with an increased availability of essential nutrients like nitrogen, phosphorus, and potassium (Azim et al., 2017). Additionally, qualities like pH-adjustment and moisture regulation can promote microbial support and plant growth.

1.2 Aim

The aim of this study is to investigate the physical quality, as well as the chemical content and microbial activity, in three different compositions of compost made of SMC, apple waste and wood chips. The analysed data collected from the investigations will be used in subsequent studies.

1.3 Research questions

The mix of SMC, apple waste and wood chips is believed to be a promising combination for the use as fertilizer and soil amendment in fruit production. Research questions to be answered are:

- What are the physical, chemical, and microbial qualities of one- one year old compost originated from a mixture of SMC, apple wastes and wood chips?
- What is the impact of the different proportions in the originated material on compost quality?

Hypotheses for this study are:

- The investigations will show significant differences between the treatments.
- The mix of SMC, apple waste and wood chips are suitable as a fertilizer in fruit production.

2. Materials and method

2.1 Compost materials

The compost materials used in this study originate from three different reusable waste streams; Spent mushroom compost (SMC), apple waste and wood chips. They were proportioned as follows:

A- 33% apple material : 33% SMC : 33% wood chips
B- 25% apple material : 50% SMC : 25% wood chips
C- 40% apple material : 20% SMC : 40% wood chips

The SMC is provided by mushroom producers of Torna Hällestad and Saxtorp Svamp. The apple material is provided by Äppelriket and the apple orchards of Österlen in the south of Sweden, along with wood chips from its nearby growing areas and shelterbelts. Äppelriket was also the location of where the materials will be composted and where they eventually will be used as soil amendments. All three treatments have been composted for approximately a year under the same conditions. All materials have been composted in piles directly on the ground to implement simplicity, making the compost settings more accessible (see appendix 1, Figure 7). Three replicates of each treatment were randomly selected when collecting samples. A peat-based soil from the company Hasselfors Garden called Hasselfors Special had the function of reference material and contributed with reference values since the investigation also aims to replace peat-based products. The reference material was called control group D.

2.2 Experimental setup

The investigations were performed in the laboratory and the greenhouse facilities of Vegetum in Alnarp. The experiments followed a Standard Operation Procedure (SOP) divided into three sections observing three different parameters: physical, chemical, and microbial qualities of the compost treatments. The experiments were performed during a period of four weeks.

2.2.1 Nutrient analysis

The chemical properties of the compost were analysed through measuring the amounts of nutrient solution in the compost. Samples of five grams of each compost and control were collected and sent to the LMI-laboratory in Helsingborg for Spurway-analysis.

2.2.2 EC and pH measurements

Analyses of pH and EC were conducted through measuring the sample solution of each replicate of each treatment. Samples of 20 g compost and 100 ml of water were mixed in plastic bottles making it altogether ten samples including the control. The samples were then placed in a rotary shaker for an hour to completely solve the sample substrate. EC and pH were then measured in the solution after the shake with a portable pH/EC-meter: Hanna pH / EC / C - mod. Combo (Waterproof).

2.2.3 Physical quality measurements

Measurements of density

The physical qualities were quantified through measurements of bulk and compact density. The numbers were later used to calculate the porosity of the compost material. Bulk density was measured using an iron volumeter in the size of a 0,9 dm^3 cylinder. Each of the four treatments were pressed down into the cylinder for three minutes and the compacted substrate were then weighed.

Compact density was measured to calculate the weight of the composted material itself without the pores. Analyses were performed in the greenhouse facilities using 50ml samples from each replicate and treatment. The samples were put into volumetric flasks of 100 ml and was then weighed and controlled. 25 ml of Ethanol (99,5%) was then added and the flasks were put on a shaker for 30 minutes. All samples were then weighed once more, subtracting the weight of flask to learn the saturated weight of the substrate. The difference between the saturated weight and the dry weight was then used to calculate compact density, the volume of the pores, and the percentage of porosity for each replicate and treatment.

Water-holding capacity

To determine the water-holding capacity, both wet weight and dry weight was measured on all the ten replicates. The equipment used for this analysis was a plastic pot in the shape of a 0,9 dm^3 cylinder with holes in the bottom that was covered with a tissue. An extra ring was used, letting the compost material soak up water. The cylinder together with the extra ring was filled with substrate and then soaked in water for four days. When the substrate had been completely saturated it was left to drain for another 24 hours. The fully soaked substrate was then weighed and was thereafter left to dry at 105 °C for seven days. The dry weight was then weighed to calculate the water-holding capacity of the substrate treatments.

2.2.4 Microbial enumeration and analyses

Analyses of microbial growth were conducted under sterile conditions in the laboratory using the method of spot technique on four different agar medias. The four selective media targeted general bacterial flora, general fungal flora, *Pseudomonas spp.*, and *Enterobacteriaceae spp*. The preparative work for the microbial enumeration involved the preparation of agar dishes and detergent. A 200 ml detergent solution was prepared by mixing 1,7 g NaCl and 200 ml of distilled water in an Erlenmeyer flask to achieve a concentration of 0,85% NaCl. The solution was then autoclaved for an hour at 121 °C. The selective agar media were prepared as needed by mixing the ingredients, listed in Table 1, in Erlenmayer flasks which were then autoclaved for an hour at 121 °C. After cooling, the agar media were poured into sterile petri dishes.

Substrate samples were prepared by collecting 5 g of each compost substrate replicate and mixing it with 12,5 ml of detergent solution containing 0,85% NaCl. A total of ten samples were prepared, including the reference value of the control sample. The soil samples were then placed in a shaker for one hour before preparing a serial dilution for each replicate. A volume of 4,5 ml of sterile NaCl was added to test tubes. Aliquots of 0,5 ml of soil sample were serially diluted from a range between 10 and 10^{-5}. For TSA- and KB-medias dishes were inoculated with four diluted solutions ranging from 10^{-2} – 10^{-5}, while the range of 10^{-0} – 10^{-3} were used on MA- and VRBD-medias. Two agar dishes per replicate were pipetted with 50 µl of each suspension by using spot technique (see Appendix 1, Figure 8). All dishes were then covered with parafilm and stored for incubation as specified in Table 1. Enumeration of microbiota and analysis were performed manually by counting the colony-forming units (CFU) on the selective media. The estimated plate count was then used to calculate mean values of CFU/g soil for each treatment.

Table 1: *The four agar medias and selected targets for microbial enumeration*.

Medium name	Selected microbiota	Ingredients/1000ml	Incubation temperature (Celsius)	Incubation time/hours
Tryptic Soya Agar (TSA)	Enumeration of general bacterial micro flora	(Tryptone Soy Agar: 4g Bacto Agar: 15g Aq destad: 1000ml)	25	24
King's B Agar (KB)	Enumeration of *Pseudomonas spp.*	(Proteose peptone: 20g, K_2HPO_4: 1,5g, $MgSO_4$: 1,5g, Glycerol (99%): 15ml Bacto Agar: 15g Aq destad: 1000ml)	25	24
Malt extract (MA)	Enumeration of general fungal flora	(Bacto Malt Extract: 10g Bacto Agar: 20g Aq destad: 1000ml)	25	48
Violet Red Bile Dextrose Agar (VRBD)	Enumeration of *Enterobacteriaceae spp*.	(Proteose Peptone: 7g, Yeast extract: 3g, NaCl: 5g, Bile salts: 1,5g, Glucose: 10g Neutral red: 0,03g Crystal violet: 0,002g, Bacto Agar: 13g, Aq destad: 1000ml)	25	24

The dilution series of treatment C.3 was at a later moment recreated with a higher suspension ranging from 10^{-0} – 10^{-8} due to an initially suspected error. The microbial growth of C.3 showed a significantly faster growing rate in the first sample, making it impossible to count CFU after incubation.

2.3 Statistics

All statistical analyses were performed in GraphPad Prism 9.5.1 for Windows through the method of one-way analysis of variance (ANOVA). Tukey's test was used to find statistical significance of mean values between the studied groups with $p > 0,05$ considered significant. In this study, statistical analyses did not include values from control group D as it was solely used as a reference.

3. Results

3.1 Chemical parameters

3.1.1 Nutritional contents

The analysis of the nutritional contents of the taken samples revealed that treatment B had significantly higher rates of nitrogen and nitrate-N compared to treatments A and C, as shown in Figure 1 and Table 2. Treatment B also demonstrated higher ratios of nitrate-N to ammonium-N, along with the highest overall rate of plant available nitrogen. Treatment A had a higher rate of ammonium-N compared to nitrate-N, as indicated by the mean values presented in Appendix 1, Table 2. Treatment C showed equal values of ammonium-N and nitrate-N. The reference values of nitrogen concentrations in control group D were excessively high and not suitable for comparison with the compost treatments (see Appendix 1, Table 2).

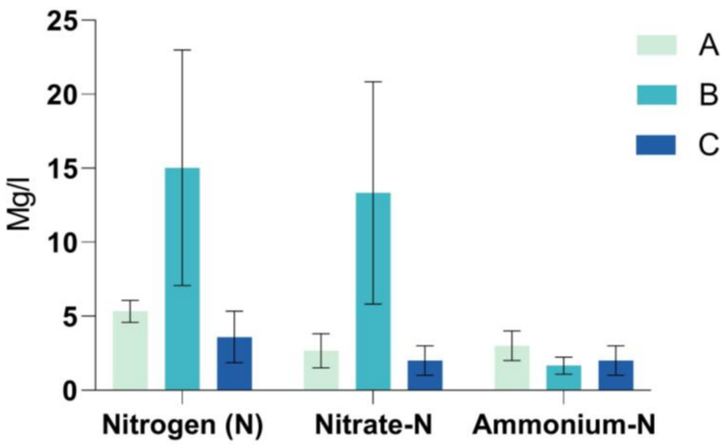

Figure 1*: The results of nutrient analysis of nitrogen concentrations in mg/L. The graphs show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. Error bars denote standard deviation. The reference value of control group D is not displayed due to its high concentrations (see Appendix 1, Table 4)*

__Table 2:__ The nitrogen concentration of nitrogen (N), nitrate-N and ammonium-N. The table show the p-values based on mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. Statistical significance was found in the concentration of nitrate-N, between treatments B and C based on Tukey's test at p ≤ 0.05 within columns.

	Nitrogen			Nitrate-N			Ammonium-N		
Treatment	A	B	C	A	B	C	A	B	C
Mean	5,3	15,0	3,6	2,7	13,3	2,0	3,0	1,7	2,0
P-value (vs. group A)	-	0,100	0,896	-	0,058	0,981	-	0,232	0,404
P-value (vs. group B)	0,100	-	0,057	0,058	-	0,046	0,232	-	0,891
P-value (vs. group C)	0,896	0,057	-	0,981	0,046	-	0,404	0,891	-

No signifiant differences were found in the results of the macronutrient contents among the treatments. However, all of the treatments displayed higher values compared to the reference group D as shown in Figure 2. Treatment B had the highest nutrient values, followed closely by treatment A. Apart from reference group D, treatment C had the lowest values of nutrients. All compost treatments showed equal levels of phosphorus and sodium levels were relatively low. A high amount of calicum is also evident in the results. The contents of micronutrients are presented in Appendix 1, Table 2, and did not show significant differences among the treatments.

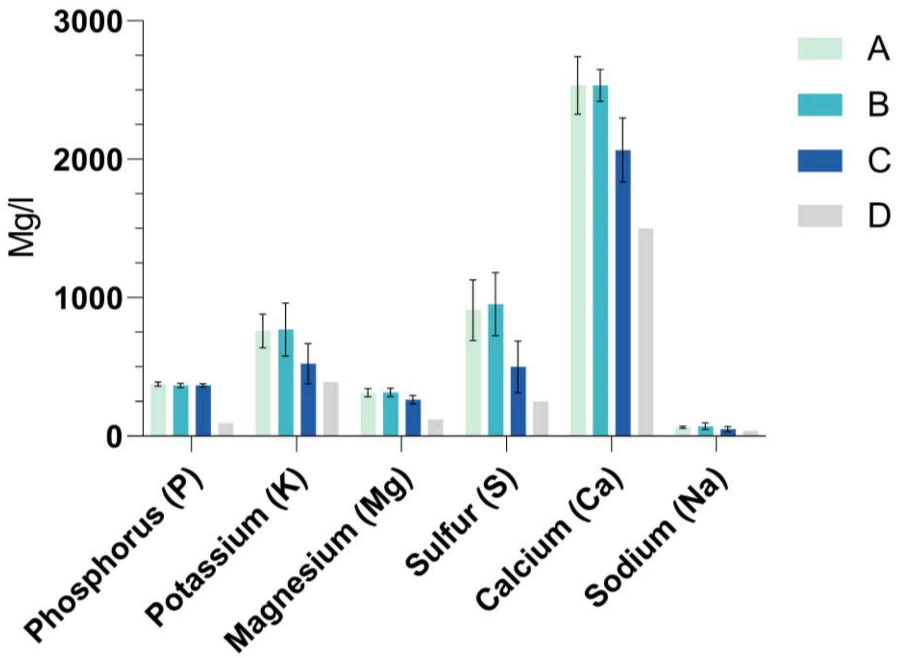

__Figure 2:__ Values of macronutrients and sodium (Na) in mg/L. The graphs show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. D = Peat-based soil (reference value). Error bars denote standard deviation. The P-values for each analysed group are as follows: (P): 0,269, (K): 0,169, (Mg): 0,133, (S): 0,072, (Ca): 0,055, (Na): 0,411. P-values show no statistical difference between treatments based on Tukey's test at p ≤ 0.05 within columns.

3.1.2 EC and pH analysis

The results from measuring pH showed very similar individual values (see Appendix 1, Table 5) with a difference of 0,33 between the highest (7.28) and lowest (6.95) values of all treatments. Mean values were consistently higher than the reference value of control group D (5.05). Statistical analyses showed no significance difference between groups, as indicated by the result of high p-values (see Figure 3).

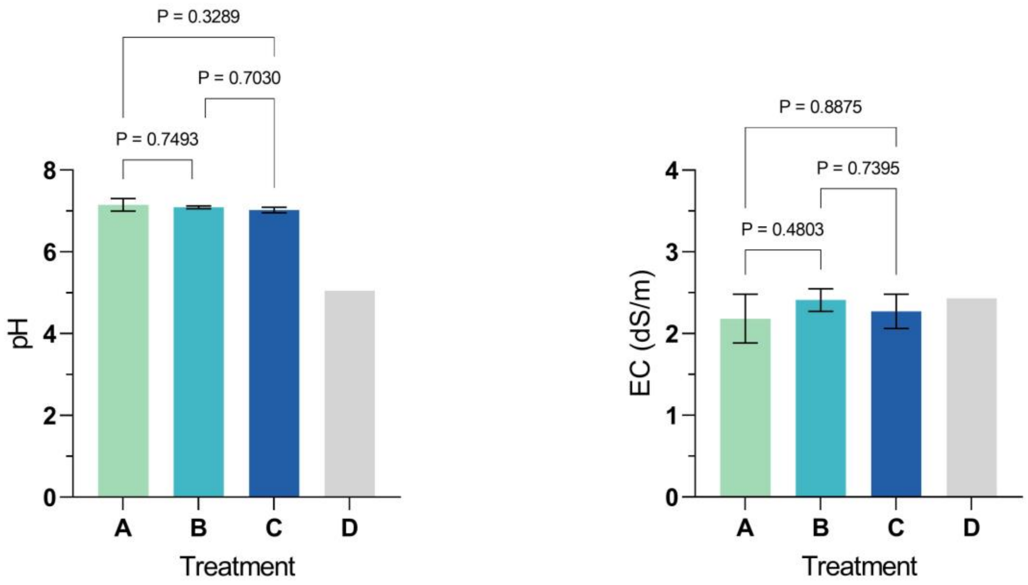

Figure 3: *The measurements of pH and EC. The graphs show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. D = Peat-based soil (reference value). Error bars denote standard deviation. Inserted p-values show no statistical difference between treatments based on Tukey's test at $p \leq 0.05$ within columns.*

The values from measuring EC gave a slightly different result. While the values still show results with means >2 dS/m, which indicates on a salinity level slightly above average (Gonani et al., 2011), all treatments show lower values against the reference group D (see Figure 3). Treatment B has the highest values, and it also contains the most SMC. Still the lack of significance between the treatments indicates no effect of the ratio of composted materials.

3.2 Physical parameters

There are little to no indications of the different treatments having any impact on the physical properties of the compost. The statistical analysis revealed no significant variations between the groups, with predominantly high p-values observed in the experiments (see Figures 4 & 5).

3.2.1 Density measurements

The compost treatments presented higher values of bulk density and compact density compared to the reference values of the control group D. The mean values of bulk density ranged between 500-600 kg/m^3, with treatment A showing the highest value. There were no significant differences between treatments B and C in terms of bulk density. As for compact density, the mean values were ranging between 1000-1200 kg/m^3. Notably, treatment B hade the highest compact density values, with no significant differences between treatments A and C. Treatment B also showed a higher dispersion rate.

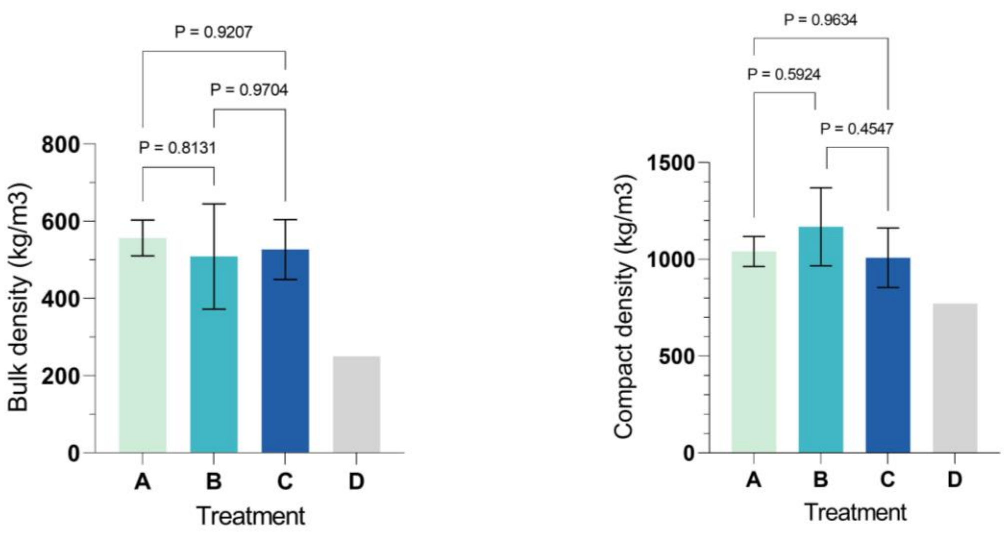

Figure 4: *The measurements of bulk- and compact density. The graphs show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. D = Peat-based soil (reference value). Vertical error bars denote standard deviation. Inserted p-values show no statistical difference between treatments based on Tukey's test at p ≤ 0.05 within columns.*

3.2.2 Porosity and water-holding capacity (WHC)

The results of the porosity and WHC calculaltions showed control group D had the highest values in both investigations. There was a noticable correlation among the factors of compact density, porosity and WHC between the treatments (see Figures 4 & 5) where treatment B demonstrated the highest rates of both porosity and WHC, followed by treatment C and finally treatment A.

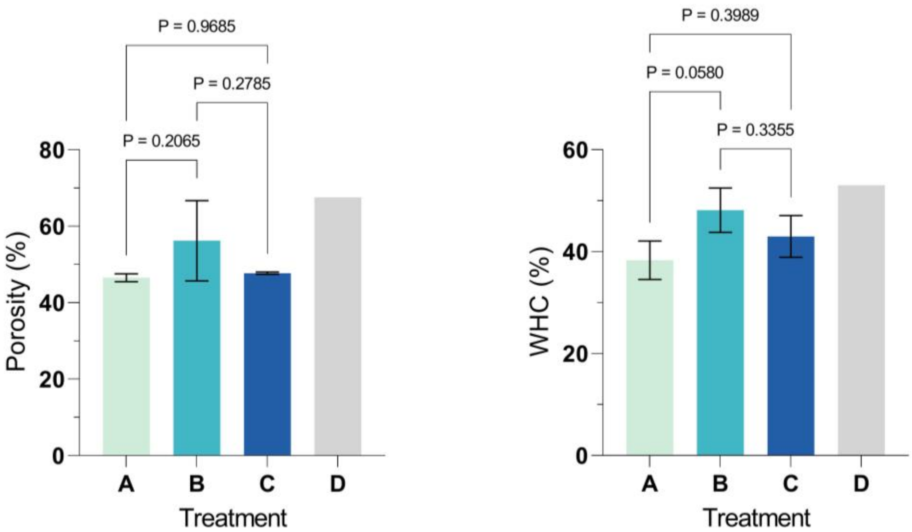

Figure 5: *The measurements of porosity and water-holding capacity in %. The graphs show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. D = Peat-based soil (reference value). Error bars denote standard deviation. Inserted p-values show no statistical difference between treatments based on Tukey's test at* $p \leq 0.05$ *within columns.*

3.3 Microbial parameters

The enumeration of microbial growth revealed that compost C exhibited the highest levels of activity, most noticeable in the growth of general bacteria and *Pseudomonas spp.* (see Figure 6). The observation is consistent with the fact that Compost C contains the highest amount of organic matter. In contrast the values of fungal growth on MA were similar among the compost treatments, indicating no impact of the compositions. The slightly elevated levels of *Enterobacteriaceae spp.* are noticeable in all compost treatment, suggesting a need for caution. When comparing the results of microbial growth, there was evidence of higher overall activity in all the compost treatments compared to the reference value of control group D. Notably, control group D showed no growth of *Pseudomonas spp*. hence the absent value of control group D in Figure 6.

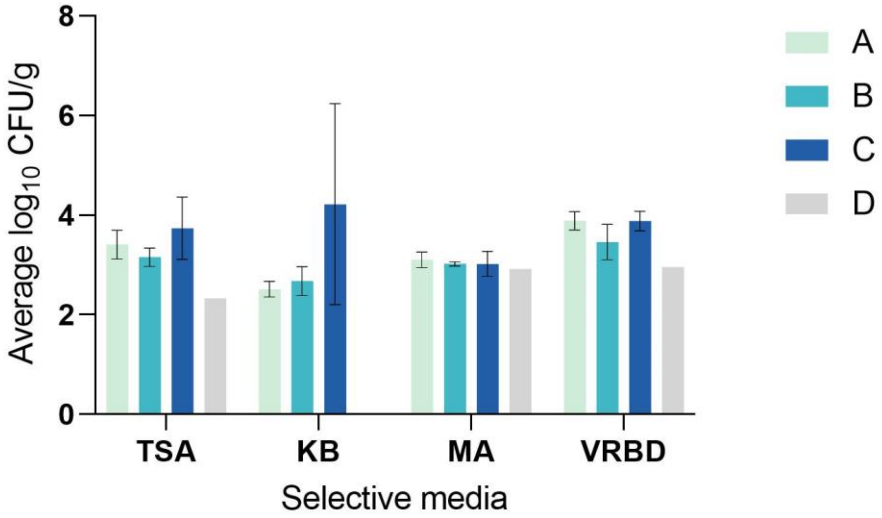

Figure 6*: The amount of microbial growth in Log10 CFU/g on selective media – Tryptic Soy agar (TSA) for enumeration of general bacteria, King's B agar (KB) for enumeration of Pseudomonas spp, Malt extract agar (MA) for enumeration of general fungal flora, Violet red bile dextrose agar (VRBD) for enumeration of Enterobacteriaceae spp. The graph shows the mean values of three treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. D = Peat-based soil (reference value). Vertical error bars denote standard deviation.*

Statistical analyses showed no variable difference between compost treatments in terms of microbial growth as presented in Table 3, and the result showed overall high p-values. Upon examining the mean values (see Table 3), the high amount of *Pseudomonas spp.* was evident in treatment C.

Table 3: *Microbial growth on selective media – Tryptic Soy agar (TSA) for enumeration of general bacteria, King's B agar (KB) for enumeration of Pseudomonas spp, Malt extract agar (MA) for enumeration of general fungal flora, Violet red bile dextrose agar (VRBD) for enumeration of Enterobacteriaceae spp. Mean values of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips. P-values reveal no statistical difference between treatments based on Tukey's test at* $p \leq 0.05$ *within columns.*

	TSA			KB			MA			VRBD		
	A	B	C	A	B	C	A	B	C	A	B	C
Mean	3,407	3,153	3,737	2,513	2,673	4,22	3,1	3,02	3,02	3,887	3,46	3,88
P-value (vs. group A)	-	0,7442	0,6156	-	0,9849	0,2563	-	0,8412	0,8412	-	0,1862	0,9994
P-value (vs. group B)	0,7442	-	0,2702	0,9849	-	0,3135	0,8412	-	>0,9999	0,1862	-	0,1938
P-value (vs. group C)	0,6156	0,2702	-	0,2563	0,3135	-	0,8412	>0,9999	-	0,9994	0,1938	-

4. Discussion

Every year, tons of organic industrial waste can be effectively utilized as sustainable and locally produced fertilizer, benefiting fruit producers. By emphasizing the importance of sourcing material from reusable streams, this study aligns with one of the main principles of circular economy by highlighting an effective recycling of organic waste (Taparia et al., 2021).

In this study, the mixture of three different materials from such sources has been analysed for its physical, chemical, and microbial properties through a series of laboratory and practical tests. The individual qualities of the components in the compost were believed to be expressed in various ways, aligning with one of the hypotheses of this study to investigate the significance of the treatments along with the impacts of the material composition. Contrary to the expectations, most of the statistical analyses did not reveal significant differences between the treatments, except the rates of nitrate. As discussed by Azim et al. (2017) and Cerda et al. (2018) the quality of compost is defined by its stability and maturity, yet the definition of stability and maturity in compost is uncertain. These characteristics are often expressed through factors such as the degree of humification, the biodegradability of the composted materials, and phytotoxicity. The maturity phase, which corresponds to the humifaction phase (or cooldown), follows the decomposition phase (the mesophilic and thermophilic stages). The maturity phase occurs during several months and involves the reorganization of organic matter into more stable molecules (Azim et al., 2017; Cerda et al., 2018; Jakubus, 2020). The results indicating insignificant similarity between the treatments could suggest that, after one year of composting, the degradation of materials has reduced the initial differences between the treatments. It is therefore possible that the age of the compost, or the rate of the composting process, has influenced the outcome of the results. A stable and mature compost is essential for its effective use as an amendment and being a source of nutrients for plants. (Jakubus, 2020).

The only finding where statistical significance could be observed were in the test results from the Spurway-analysis of the nutritional content of the compost. Compost B showed the best results in terms of nutrient content, while compost C had the lowest levels. This difference could be an indication of an impact from the

SMC ratio. Notably, compost B was the only treatment showing significantly higher values of nitrate-N compared to ammonium-N, implying a higher nitrification rate. Compost B has the richest SMC ratio at 50%, while compost C has the lowest rate. This could be related to the large number of nitrifying bacteria mentioned by Zhang and Sun (2004) present in SMC, turning ammonium-N into nitrate-N. The fairly low rates of nitrogen in treatments A and C could be an effect of a carbon-to-nitrogen (C:N) ratio imbalance, caused by an excessive amount of carbon-rich materials, in this case wood chips, resulting in slower nitrogen release (Jakubus, 2020). The overall concentrations of nitrogen did not exceed the levels of reference group D (see Appendix 1, Table 4), yet when considering phosphorus, potassium, and most of the nutrients analysed, the compost treatments individually displayed higher values. This establishes diversity in the nutrient contents among the compost treatments. It is important to note that a peat-based soil was not a suitable reference for this test due to its rich nitrogen content (Taparia et al., 2021). Nonetheless it provided interesting results, as one of the objectives for this study is to find a substitute for peat as a fertilizer.

Another interesting finding is the results regarding the investigations for pH and electrical conductivity (EC) revealing relatively high pH-values around 7.0, and salinity level between 1,5-3 dS/m for all the treatments. Both factors are suitable for apple cultivation (Uzun, 2004). Values exceeding 4 dS/m is considered the threshold that inhibits plant growth (Gonani et al., 2011). Then again, the results from the Spurway-analysis showed a different result (see Appendix 1, Table 4) and none of the treatments had EC-values below 4 dS/m. Given that the main limitation of SMC is its high content of soluble salts (Catal and Peksen, 2020), the observed higher salinity levels are not surprising.

Earlier studies have shown that even after a prolonged period of decomposition, salinity levels remained high in SMC suggesting the earlier mentioned need to be mixed with other media (Gonani et al., 2011; Uzun, 2004). This might imply that the combination of SMC, apple waste and wood chips potentially could neutralize the problematic salinity levels, despite the different outcome of results. It could be an effect caused by dilution of the concentration of soluble salts during the composting process since the apple waste and wood chips contribute with organic matter, bulk, and carbon-rich materials to the mixture (Azim et al., 2017; Guardia et al., 2019; Vandecasteele et al., 2004). Another factor could be the set-up of the compost being placed directly on the ground without a container, allowing leaching through the passing of rainwater (Uzun, 2004). The high OM content could also assist the degradation and transformation of salts by promoting microbial activity. Moreover, pH-levels between 7-9 are indicative of mature compost, whereas acidic levels are typical characteristics of immature compost (Azim et al., 2017).

The physical characteristics of the compost yielded varied results, which did not consistently demonstrate the optimal soil amending qualities. All treatments had mean bulk density values between 500 and 600 kg/m^3 which is according to a study by Uzun (2004) a typical attribute of SMC (300 – 600 kg/m^3). Higher values of density would implement more bulk weight and a decrease of porosity and air volume which is representative for most sandy soils and fine clay/silt soils (Nappi and Barberis, 1993). A bulk density higher than 1600 kg/m^3 could be critical and may restrict root growth (Nappi and Barberis, 1993).

While the values of the treatments were seemingly moderate, the calculation of porosity indicated the density of the compost being too compact. Porosity, in this case, determines the percentage of the soil volume that can hold liquid and gaseous components, and should ideally range between 80-90% (Nappi and Barberis, 1993). The percentage of porosity varied with 45-60% between the compost treatments, the highest value observed in reference group D. WHC of the treatments, ranged from 35-50%, which correlates with the soil porosity, the optimal range being 50-60% of the composts total volume (Agnew and Leonard, 2003)._The most prominent values of the composts were given by treatment B with the highest SMC ratio as shown in Appendix 1, Table 6. Compact density, porosity and WHC relates to higher values of pore volume stating that the composition of compost B is the most optimal of the treatments after one year.

Reviewing the results of microbial growth on selective media confirmed no statistical significance between treatments. However, treatment C, which had the highest levels of OM, showed higher counts of general bacteria and *Pseudomonas spp.*. This suggests a positive occurrence of microbial diversity, including of plant growth-promoting rhizobacteria (PGPR) such as *Pseudomonas fluorescens*, which can have antagonistic effects on plant pathogens (Taparia et al. 2021). The different compositions of treatments did not have an impact on growth of general fungal flora.

The relatively high values of bacteria in VRBD-media may indicate the presence of potentially harmful *Enterobacteriaceae spp*., which should be investigated to avoid the spread of human pathogens (Hassen et al., 2001). No correlations were observed between the nutrient contents and microbial activity of treatment B and treatment C, as their high, and respectively low nutrients contents did not correspond to the values of microbial growth. Still, the high bacterial count in treatment C could be an impact of the larger amounts of OM.

While the process of composting still is being refined, new ideas of achieving a more circular system through managing waste has become more and more of interests for fruit producers. In Swedish apple cultivation, the availability of the studied material provides a consistent resource for sustainable practises. The convenience of reusing organic waste material in direct connection to the production site holds significant economic and environmental value. While mineral fertilizers can boost crop productivity by quickly providing nutrients, their excessive and long-term use can ultimately harm soil fertility (Carricondo-Martinez et al., 2022). Based on the current qualities of the compost, the result of this study suggests promising properties that requires further investigation particularly over an extended period, to determine its suitability as soil amendment and fertilizer for apple production.

5. Conclusions

This study found no statistically significant difference in the physical and microbial qualities of the compost among the treatments. Still, the compositions of the treatments could have influenced the results. The lack of statistical difference could also imply that the compost had reached a more mature and stabilized state after one year of composting indicating successful decomposition and nutrient transformation processes.

Statistical significance was observed in the analysis of nitrogen concentration, implying that the SMC ratio could contribute to the nutritional variation between the treatments. This is supported further by the overall higher nutrient content in the compost treatments compared to the reference value of control group D. Specifically, the 50% SMC ratio in treatment B, demonstrated a significantly higher nitrification rate than the other treatments. Also, the combination of SMC, apple waste and wood chips appeared to have a positive effect on reducing salinity levels in the compost, although additional research is needed to explore this further.

The compost in its current state needs further investigation to fully understand its potential as fertilizer and soil amendment in apple cultivation. Field studies should be conducted to evaluate and explore its effects on soil and apple crop. It would also be beneficial to study the properties of the compost after a longer period of decomposition to gain insights into its long-term effect and stability.

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Appendix 1

Figure 7*: Set-up for the compost treatments A, B & C at Äppelriket, Österlen (Merkert, 2023)*

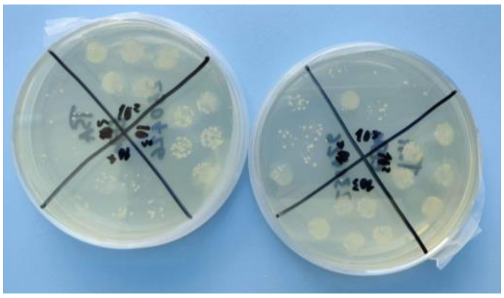

Figure 8: *Close up on a petri dish displaying colonies of general bacterial growth on TSA. (Ek Moreau, 2023)*

Table 4: *Showing the results from the Spurway-analysis at LMI. The table show the mean values of three replicates of treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips.*

Nutrient analysis (mg/l)	A	B	C	D
pH	7,5	7,5	7,3	5,4
EC	6,9	7,5	4,4	6,4
Nitrogen (N)	5,3	15	3,6	540
Nitrate-N	2,7	13,3	2	530
Ammonium-N	3	1,7	2	7
Phosphorus (P)	377	367	367	93
Potassium (K)	760	770	523	390
Magnesium (Mg)	313	317	263	120
Sulfur (S)	910	953	500	250
Calcium (Ca)	2533	2533	2067	1500
Manganese (Mn)	2,2	2	2,1	8,5
Boron (B)	1,7	1,8	1,6	0,9
Copper (Cu)	3,1	3,4	3,1	3,1
Iron (Fe)	1	1,4	1,2	5,8
Zinc (Zn)	37	39	36	3
Molybdenum (Mo)	0,1	0,1	0,1	0,4
Natrium (Na)	63	71,7	50,7	39
Aluminium (Al)	1	1,8	1,1	6,4
N-min (0-20cm) = (kg/ha)	11	30	7	1075

Table 5: *Showing the individual values of each replicate from the pH and EC-analysis. treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips.*

Treatment	pH	EC
A.1	7,19	1,84
A.2	7,28	2,32
A.3	6,98	2,39
B.1	7,12	2,49
B.2	7,1	2,25
B.3	7,05	2,49
C.1	7,08	2,36
C.2	7,04	2,42
C.3	6,95	2,03
D (control)	5,05	2,43

Table 6: *Displaying the calculated measurements of density. Individual values of each replicate. treatments A = 33% apple material / 33% SMC / 33% wood chips, B = 25% apple material / 50% SMC / 25% wood chips, C = 40% apple material / 20% SMC / 40% wood chips.*

Treaments	Pore volume (l)	Porosity	Density, bulk (kg/m3)	Density, compact (kg/m3)
A.1	0,0238	47,60%	512,00	977,10
A.2	0,0228	45,60%	554,00	1018,38
A.3	0,0232	46,40%	604,00	1126,87
B.1	0,0237	47,40%	514,00	977,19
B.2	0,0267	53,40%	642,00	1377,68
B.3	0,0339	67,80%	370,00	1149,07
C.1	0,0239	47,80%	560,00	1072,80
C.2	0,0237	47,40%	438,00	832,70
C.3	0,0240	48,00%	582,00	1119,23
D	0,0338	67,60%	250,00	771,60