Wool you look at that?

- Sheep wool pellets as fertilizer in container-grown crops with short cultivation time

Fårullspellets som gödselmedel i krukodling med kort kulturtid

Joy Hill

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Abstract

Sheep wool pellets (SWP) is an organic fertilizer that capitalizes an excess waste product of sheep husbandry, providing a way to reduce the environmental impact of wool and recycling it back into the production cycle. With a NPK of 10-0,1-4,5 and other trace elements, the pellets are considered a well-rounded fertilizer, but with a long degradation time. To investigate if sheep wool pellets can be used in shorter cultivation times, a container experiment was conducted to test if the pellets have an effect on 5-week cultivation of basil. Treatments were 0 (control), 5, and 10 g SWP/L in peat, compost, and mixed substrate of peat and compost. The result of this experiment indicates that the added amounts of sheep wool pellets does not have any effect on growth or final yield in short duration container cultivation.

Sheep wool pellets might however have other properties that still make it an interesting substrate amendment for crops with short cultivation time, such as providing higher water use efficiency and a swelling effect that results in airier substrates, facilitating better gas exchange.

Keywords: sheep wool pellets, organic fertilizer, biofertilizer, container cultivation, basil

Sammanfattning

Fårullspellets är ett organiskt gödningsmedel som nyttjar en restprodukt från fårproduktion och möjliggör en minskad miljöpåverkan från ullrester genom att återvinna den tillbaka in i produktionscykeln. Med ett NPK på 10-0,1-4,5 och även höga nivåer av mikronäringsämnen anses pelletsen vara ett allsidigt gödselmedel, men med lång nedbrytningstid. För att undersöka om fårullspellets kan användas under kortare kulturtider genomfördes ett containerförsök för att se pelletsen effekt efter 5 veckors odling av basilika. Behandlingarna var 0 (kontroll), 5 och 10 g SWP/l i torv, kompost och blandat substrat med torv och kompost. Resultatet indikerar att de undersökta mängderna fårullspellets inte har någon effekt på tillväxt och slutlig skördemängd vid kortvarig krukodling.

Fårullspellets kan dock ha andra egenskaper som gör dem till intressanta substratförbättrare även för kortare kulturtider, exempelvis högre vattenanvändningseffektivitet och luftigare substrat.

Keywords: fårullspellets, organisk gödsel, biogödsel, krukodling, basilika

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Abbreviations and technical terms

Bulk density (BD)	Mass/density of dry substrate, including both solids and air filled pores (g/dm^3).
Compact density (CD)	Density of substrate, excluding open air filled pores (g/dm^3). True dry weight in relation to volume.
Porosity	Amount of total volume that is pores (%).
SWP	Sheep wool pellets
Water holding capacity (WHC)	Water retention (%) of a substrate. Plant available water after drainag

When wool and pellets is mentioned it is in regards to sheep wool and sheep wool pellets, unless otherwise specified.

Abbreviations treatments

P0	Peat (no SWP)
P5	Peat + SWP 5 g/l
P10	Peat + SWP 10 g/l
C0	Compost (no SWP)
C5	Compost + SWP 5 g/l
C10	Compost + SWP 10 g/l
M0	Mix (no SWP)
M5	Mix + SWP 5 g/l
M10	Mix + SWP 10 g/l

1. Introduction

Global sheep (*Ovis aries*) population is currently at approximately 1 billion animals, 450 000 of which are found in Sweden (Sjödin et al. 2008). Sheep not only provide meat, wool, milk and skin, but also environmental services (Sjödin et al. 2008). Their grazing opens up habitats, ensuring the conservation of open landscapes while also being less time consuming and cheaper to keep when compared to other domestic livestock (Sjödin et al. 2008). However, it can be difficult to make a financial profit on sheep husbandry, which has led to a constant search for added value to the production.

The number of sheep on earth has hardly changed over the last 70 years (Sjödin et al. 2008). What has changed is the main focus of production, with a shift towards meatier sheep and often at the expense of wool quality (ibid). Synthetic fibers have replaced wool and demand has been on a steady decline in the last century. Whether kept for milk, meat or wool, a sheep annually produces approximately 1,5 to 3 kg wool and must be sheared at least once a year (Sjödin et al. 2008; Petek & Logar 2021). Shearing is a time-consuming and labor-intensive task and removing and handling sheep wool waste usually equals a cost that farmers cannot recoup from the wool itself (Sjödin et al. 2008). Today, the average wool production in the EU exceeds 200 000 tons, consisting of mainly coarse and low grade wool (Zoccola et al. 2015). This wool is often considered a waste and a by-product that is either burned, dumped or sent straight to landfill and finding safe ways to dispose of this surplus organic waste is beneficial for both farmers and consumers (Petek & Logar 2021).

Producing more food on less land is required to support our growing population. But it needs to be done in a more sustainable way with, at the very least, a neutral environmental impact. Ammonia fertilizer production alone is responsible for 1-2% of worldwide carbon dioxide emissions (Manthiram & Gribkoff 2021). One way to reduce nitrous oxide emissions, without sacrificing crop yields, is using slow-release fertilizers (ibid). Using sheep wool as fertilizer is not only recirculating nutrients, as it is biodegradable the natural breakdown also makes nutrients continuously available to the plant over a long period of time (Ordiales et al. 2016; Lal et al. 2020). Trials have been conducted in both field and greenhouse environments with promising results, but there are still questions in regards to how and when is to be applied, depending on the crop and cultivation method.

One factor that is not well-known is the rate of breakdown and exactly how long it takes for the nutrients to become plant available. In addition, the participation of soil microbes (bacteria, fungi) in improving availability of mineral nutrients in rhizosphere has been reported and especially under field conditions (Xu et al. 2018). However, the microbial aspect of influencing the rate of mineral nutrient release from wool pellets was deemed beyond the scope of this thesis.

1.1 Objective and research question

The goal of this essay is to evaluate sheep wool pellets to see if it can serve as a fertilizer for container-grown and short cultivation crops. The experiment evaluation was made by observing and comparing the growth and final biomass in basil after a cultivation period of 5 weeks.

Research questions:

- Does fertilizing with sheep wool pellets affect the yield in short term container-grown crops?
- What are the physiological properties of SWP and how can they affect container cultivation?

1.2 Limitations

This report only addresses pelletized sheep wool. It does not go into sheep wool hydrolysis and treated sheep wool, except for the heat-treatment during pelletization. It does not investigate differing nutritional composition or levels of aromatic compounds in the harvested crop, only the weekly growth and final yield. In addition, the microbial aspect of influencing the rate of mineral nutrient release from wool pellets was recognized but was deemed beyond the scope of this thesis. This experiment was conducted under a limited time and may, if possible, could have been extended.

2. Material and method

2.1 Material

2.1.1 Sheep wool pellets (SWP)

The pellets used were made by wool from Ullkontoret, situated in Endre (Gotland, Sweden). The wool is raw, meaning it is not washed or otherwise treated before being made into pellets. First step is cutting the wool to 5-7 mm, then drying it down to 15% moisture in a temperature of 80°C for 1-1,5 hours. It is then exposed to temperatures ranging between 80-120°C while being under a pressure of 400-650 bar, depending on the wool thickness. The final pellets have a diameter of 6 mm and are heated at 80°C for an additional hour and then cooled down to approximately 20°C before being packaged.

2.1.2 Substrates

The compost was from Sysav (Malmö, Sweden) and a 1:1 mixture of fractions 0-10 and 0-20. The compost was certified and produced from park- and garden waste from surrounding waste facilities. It has no additives. The inorganic nutrient consist of mainly potassium, phosphorus and calcium, it was plausible that the level of plant-accessible nitrogen is low (Sysav 2020).

The peat is pure sphagnum without any additives, a humification value of H 2-4 and natural pH level of 3,5 to 4,5 (Hasselfors Garden AB 2020). The compost and peat was also used as a mixed substrate with 3:7 ratio, a common ratio found in store-bought potting soil.

2.1.3 Plant material

The plant used in the cultivation experiment was basil, *Ocimum basilicum,* ‘Genovese’ with seeds from Ohlssons frö AB (Helsingborg, Sweden). Basil is a herb from the Lamiaceae family that requires low levels of fertilizer, 100-150 ppm N is enough when grown in containers (Owen et al. 2018). If under-fertilized, basil exhibits signs of chlorosis and stunted growth. Overfertilizing leads to excessive growth and larger leaves, which in basil leads to reduced oil content and flavour (ibid). For basil production, pH should be kept within the range of 5.8-6.2 (ibid). pH below 5.8 increases iron and manganese uptake which accumulates in leaves and can lead to chlorosis of lower leaves, while levels above 6.5 inhibits plant uptake of iron which exhibits as interveinal chlorosis (ibid).

2.2 Method

2.2.1 Substrate and sheep wool properties

The characteristics were determined by following lab instructions from the course Hydroponic Systems in Horticultural Production and Public Environment BI1233 (Asp 2021). In each test four measurements of each substrate were made, using the mean value in calculations and as results.

Bulk density was determined by using an iron cylinder with spacer ring. First the cylinder was overfilled with substrate and then, using a ruler, excess substrate was removed without compressing the substrate. A weight was added on top of the substrate for 3 minutes before being removed. The spacer ring was then removed, and abundant substrate scraped off with the ruler. Remaining substrate was emptied into a container and weighed, after which the bulk density (g/dm^3) was calculated.

Compact density was measured using 50 ml volumetric flasks. Each flask was weighed first empty and then half filled with the substrates. Using a burette, they were then filled with 25 ml methylated spirits, sealed, and put in a shaker for 30 minutes. After that, methylated spirits were again added until the 50 ml mark was reached. Volume was calculated using the total amount of added spirits and substrate weight. Using compact and bulk density, the volume percentage of pores (porosity) could also be calculated.

The different substrates water holding capacity in pots was determined by filling cylinders and their cylinder extensions with substrate, up to approximately 2 cm from the upper edge. The bottom of the cylinders had a grid and was equipped with gauze. The cylinders were then placed in a container which was slowly filled with water, up to just 2 cm below the edge of the cylinders. After two days of water saturation, the cylinders were moved from the container, covered in plastic foil, and allowed to drain for 24 hours. The extensions were then taken off and excess substrate was removed before emptying the cylinder contents into containers. The containers were weighed without and then with wet substrates before they were all put in drying cabinets for two days and then weighed again. Sheep wool was weighed but then put back into the drying cabinet for an additional day as it still felt slightly moist. Worth noting is that the wool was not necessarily still holding fluids but that the experienced moisture might have been melted fats in the wool.

2.2.2 Basil cultivation

Seeds of basil, *Ocimum basilicum* ‘Genovese’, were planted at a depth of approximately 2 mm in sowing soil, “s-jord” from Hasselfors Garden AB, Örebro, Sweden. After 25 days, when the first character leaves had developed, the plants were transplanted to new pots. Ten plants were placed in each pot of 1,5 L volume which was filled with 1,2 L of substrate, each pot with its own saucer. Three days after planting the pots were randomly distributed on a gridded table (3 m × 1,6 m) at a plant density of 15 plants/m^2.

The experiment consisted of 8 containers per treatment with 9 replications, a total of 72 pots. The replications had peat, compost (1:1 mix of fractions 0-10 and 0-20) or a mixture of the two (7:3, peat and compost) with either 0, 5 or 10 g of added sheep wool pellets. SWP was placed approximately 5 cm below the substrate surface by filling the pot with soil then adding pellets before topping it off with the remaining soil.

Table 1. Treatments and their abbreviations

P0	Peat (no SWP)	C0	Compost (no SWP)	M0	Mix (no SWP)
P5	Peat + SWP 5 g/l	C5	Compost + SWP 5 g/l	M5	Mix + SWP 5 g/l
P10	Peat + SWP 10 g/l	C10	Compost + SWP 10 g/l	M10	Mix + SWP 10 g/l

From sowing to harvest, the plants were kept in a controlled greenhouse environment with 14 hour light/day. Day temperature was kept at 20°C and lowered to 18°C during the night. Day temperature was lowered to 18°C 20 days into the experiment to accommodate other experiments conducted in the shared greenhouse area. The culture was watered twice a week from above with no added fertilization. A total of 13 dl of water was used for compost and mixed substrate. Peat was used a total of 10,5 dl and was mainly watered less at the end of the experiment as the plants had not grown as much as the other two. Gnatrol® SC (Nordisk Alkali, Malmö, Sweden), *Bacillus thuringiensis* subsp. *israelensis*, was applied in week 2 and 3 to all pots to control fungus gnats.

Measuring was done one week after planting and then once a week for the remainder of the experiment. The height of the plants was measured from the brim of the container to the top of the tallest plant in each pot. The experiment was concluded 60 days after sowing and 35 days after transplanting. Each pot was cut at the brim of the container. The height of each plant was then measured individually. The resulting biomass of each pot was weighed both directly after harvest and after 3 days in a drying cabinet set at 60°C, e.g. fresh and dry weight.

2.2.3 Statistic analysis

Data collected during the cultivation test was run through Minitab and evaluated using analysis of variance, ANOVA, to compare the different treatments using a significance level of 5% (Englund 2022). Where significant differences were discovered, the ANOVA-test was followed by the post hoc test Tukey's (HSD) to determine where those differences lie (ibid).

2.2.4 Nutrient analysis

Sheep wool is an organic product which means pH, EC and nutrient composition might differ depending on origin and the type of wool and sheep, and if materials are removed or added in the process of shearing and in the pellets production. Samples of the sheep wool pellets were therefore sent to LMI AB (Helsingborg, Sweden) for a modified Spurway analysis, showing pH, EC and the amount of plant nutrients that are or will be available in the upcoming few weeks. Samples were taken from both before planting and after harvest. The samples sent after harvest was taken from a blend of substrate from four pots of each treatment.

The sheep wool was also sent for additional analysis to Eurofins Environment Testing Sweden AB (Lidköping, Sweden) to determine the complete nutritional profile of the pellets. Note that this test does not determine when the nutrients will be made available to plants, only that they are present.

3. Results

3.1 Properties of Sheep Wool Pellets

All substrates had a high porosity, >60%, and a high water holding capacity, >65% (Table 2). Bulk density of SWP was measured twice: before and after being soaked and then redried. SWP had a bulk density (BD) of 502,31 and expanded SWP had a BD of 101,50 g/l, meaning the pellets have an expansion factor of approximately 5.

Table 2. Physiological properties of SWP and substrates.

	Bulk density (g/l)	**Compact density (g/l)**	**Porosity**	**Water Holding Capacity**
SWP	502,3	1282,1	61 %	72 %
Compost	598,4	1393,4	57 %	89 %
Peat	295,9	1166,1	75 %	65 %
Mix	381,4	1292,4	71 %	76 %

3.1.1 SWP Nutrient Analysis

N-P-K of sheep wool pellets is 10-0,1-4,5 (Table 3). About 1,5% of the nitrogen is readily available ammonium ions while the rest needs to be broken down before it can be taken up by plants. SWP has a high pH between 8.3-8.6 and electric conductivity (EC) of 2,8 mS/cm.

Table 3. Total nutrient composition of Sheep Wool Pellets

Total Nitrogen (N)	102,5	kg/ton	Calcium (Ca)	3,7	kg/ton
Ammonium-N (NH_4-N)	*15,0*	*kg/ton*	Magnesium (Mg)	1,0	kg/ton
Phosphorus (P)	0,9	kg/ton	Sulfur (S)	24,0	kg/ton
Potassium (K)	45,5	kg/ton			

3.2 Substrate nutrient analysis

Table 4. Peat: Plant available nutrients before and after cultivation of basil plants.

		Before			After		
PEAT		**P0-A**	**P5-A**	**P10-A**	**P0-B**	**P5-B**	**P10-B**
pH		4,1	4,4	4,5	4	4,2	4,3
EC	mS/cm	0,22	0,55	0,84	0,64*	0,74*	0,77
Total Nitrogen (N)	mg/l	16	9,8	11	26*	31*	36*
Nitrate-N (NO_3-N)	*mg/l*	*1*	*4*	*2*	*5**	*4**	*8**
Ammonium-N (NH_4-N)	*mg/l*	*16*	*6*	*8*	*20**	*27**	*28**
Phosphorus (P)	mg/l	1	5	7	1	2	4
Potassium (K)	mg/l	10	210	400	64*	140	170
Magnesium (Mg)	mg/l	17	28	25	21*	19	20
Sulfur (S)	mg/l	6	5	8	9*	11*	12*
Calcium (Ca)	mg/l	44	49	43	70*	57*	230*
Manganese (Mn)	mg/l	0,36	0,39	0,36	0,35	0,31	0,57*
Bor (B)	mg/l	<0,28	<0,28	<0,28	<0,28	<0,28	<0,28
Iron (Fe)	mg/l	0,61	0,89	1,6	0,57	0,66	0,87
Sodium (Na)	mg/l	36	51	68	73*	80*	74*
Aluminum (Al)	mg/l	<1	1,2	2,1	<1	<1	<1

Low Good Excess

*P0, P5 and P10 refers to amount of SWP. A is before, and B is after the cultivation period. Colors indicate if the nutrient available is within LMI AB's recommendation for cultivation of basil and other greenhouse herbs. * Indicates increase in levels compared to start of experiment. Not enough datapoints to determine if there are significant differences.*

All treatments in the Peat group had a pH of <4,5, making the substrate acidic. Neither dose of SWP was enough to raise the pH to recommended levels. pH of all treatments had dropped by 0.1-0.2 at the end of the experiment compared to initial reading, this was not observed in the other groups.

Except for K, Na and Al, no amount of SWP raised the nutrients to the needed levels at the start of the cultivation period (Table 4). Peat was the only group where the amount of N was higher after the cultivation period, both N and ammonia levels had tripled for P5 and P10.

Table 5. Compost: Plant available nutrients before and after cultivation of basil plants.

		Before			After		
COMPOST		**C0-A**	**C5-A**	**C10-A**	**C0-B**	**C5-B**	**C10-B**
pH		7,7	7,3	7,4	8,2*	8,2*	8,2*
EC	mS/cm	4,4	7,7	8,2	3,1	3,8	3,6
Total Nitrogen (N)	mg/l	190	230	240	24	29	49
Nitrate-N (NO_3-N)	*mg/l*	*190*	*220*	*230*	*22*	*27*	*44*
Ammonium-N (NH_4-N)	*mg/l*	*2*	*7*	*7*	*2*	*2*	*5*
Phosphorus (P)	mg/l	130	130	130	120	120	120
Potassium (K)	mg/l	1600	2300	2500	1400	1700	1800
Magnesium (Mg)	mg/l	200	220	210	190	190	180
Sulfur (S)	mg/l	47	69	73	36	52	59
Calcium (Ca)	mg/l	1000	960	870	940	880	810
Manganese (Mn)	mg/l	1,3	1,1	1,3	1,8*	1,2*	1,8*
Bor (B)	mg/l	2,4	3,2	3,3	2,5*	2,7	2,7
Iron (Fe)	mg/l	3,2	1,7	2,7	26*	4,3*	17*
Sodium (Na)	mg/l	140	220	220	170*	190	200
Aluminum (Al)	mg/l	4,3	1,8	2,9	4,3	6*	2,7

Low Good Excess

*C0, C5 and C10 refers to amount of SWP. A is before, and B is after the cultivation period. Colors indicate if the nutrient available is within LMI AB's recommendation for cultivation of basil and other greenhouse herbs. * Indicates increase in levels compared to start of experiment. Not enough datapoints to determine if there are significant differences.*

Compost was the only group with adequate amounts of N at the start of the experiment, but those values were low at harvest (Table 5). Most nutrients had lower amounts at harvest when compared to initial reading but were still at adequate or excess levels and only N was at levels that can be considered low. Manganese and iron were the only nutrients that had increased levels in all treatments.

The compost group had initial pH >7.7, making all treatments alkaline. The substrate pH was raised even further at harvest and across all treatments, with or without SWP, and registering a pH of 8.2.

Table 6. Mixed substrate: Plant available nutrients before and after cultivation of basil plants.

		Before			After		
MIX		**M0-A**	**M5-A**	**M10-A**	**M0-B**	**M5-B**	**M10-B**
pH		4,9	5	5,2	5,3*	5,6*	5,8*
EC	mS/cm	2,5	2,7	3,3	1,2	1,1	1,5
Nitrogen (N)	mg/l	110	92	86	8,6	11	19
Nitrate-N (NO_3-N)	*mg/l*	*93*	*79*	*75*	*4*	*3*	*4*
Ammonium-N (NH_4-N)	*mg/l*	*18*	*14*	*11*	*5*	*8*	*16*
Phosphorus (P)	mg/l	110	99	99	53	49	50
Potassium (K)	mg/l	640	840	1100	320	490	620
Magnesium (Mg)	mg/l	110	110	110	82	81	80
Sulfur (S)	mg/l	27	26	31	14	17	20
Calcium (Ca)	mg/l	340	300	360	270	260	270
Manganese (Mn)	mg/l	2,5	2,5	2,4	2,1	2,2	2,2
Bor (B)	mg/l	1,3	1,2	1,3	0,75	0,74	0,73
Iron (Fe)	mg/l	1,8	3,4	3,7	1,4	1,7	1,7
Sodium (Na)	mg/l	100	100	120	100	110	110
Aluminum (Al)	mg/l	1,9	4,1	4,4	1,7	2,5	2,5

Low Good Excess

*M0, M5 and M10 refers to amount of SWP. A is before, and B is after the cultivation period Colors indicate if the nutrient available is within LMI AB's recommendation for cultivation of basil and other greenhouse herbs. * Indicates increase in levels compared to start of experiment. Not enough datapoints to determine if there are significant differences.*

For the Mixed group the SWP raised the pH levels slightly at the start of the cultivation period and at harvest the pH levels of M5 and M10 had reached recommended levels (Table 6). All nutrients had lower levels at harvest compared to initial readings. Final N levels were below adequate levels initially and ended with the lowest values of all groups in all treatments. It also seems that adding SWP lowered the amount of nitrogen available, but that by the end of the experiment there were slightly higher levels of nitrogen in the containers with SWP compared to the control (Table 6).

3.3 Cultivation

3.3.1 Mortality

A total of 72 pots were planted with 720 plants. Each substrate contained 240 plants with 80 plants per treatment. Total mortality between the different treatments (0, 5 and 10 g SWP/l) had a *p*-value of 0,838 and showed no significant difference. SWP0 had mean of 6,3, SD of ± 4,7. SWP5 had a mean of 6,8, SD of ± 4,4. SWP10 had a mean of 7, SD of ± 3,3.

More plants in Peat survived with higher amounts of SWP but the opposite is true for the Mix (Figure 1). In total only 28 of the 240 plants grown in peat survived until harvest, all of P0 died. Peat had a *p*-value of 0, with a significant difference between P10 and the other two. P0 had a mean of 10 with SD of ± 0. P5 had mean of 9,2, SD of ± 0,886. P10 had mean of 7,25 and SD of ± 1,165. Compost had a *p*-value of 0,301 and no significant difference. C0 had a mean of 1, SD of ± 2,1. C5 and C10 had a mean of 0,125 and SD of ± 0,354. Mix had a *p*-value of 0,019 with significant differences between M0 and M5/M10 and also between M10 and M0/M5.

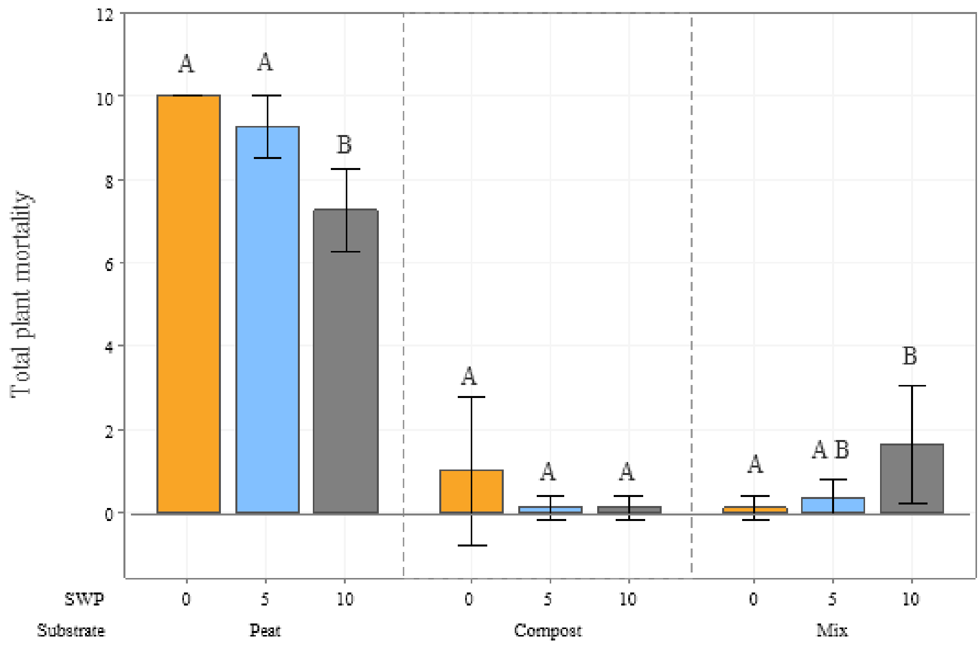

Figure 1. Total mortality of Basil plants treated with peat, compost or a mixture of substrates Means that do not share a letter are significantly different from others within their group, Peat, Compost and Mix. (Tukey-test, P<0,05).

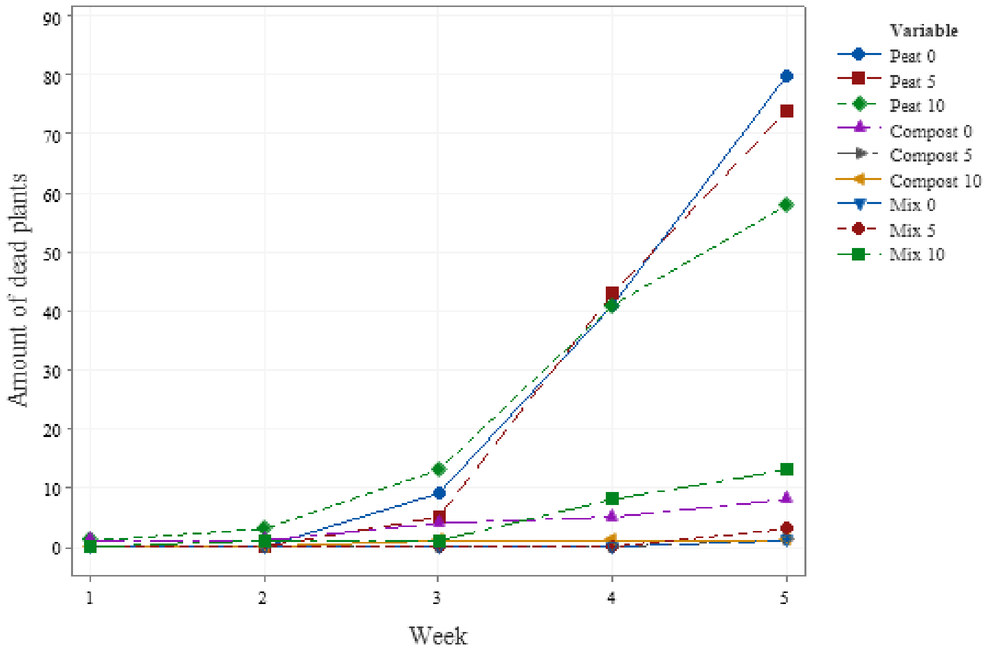

Figure 2. Mortality over time of Basil plants treated with peat, compost or a mixture of substrates

Most plants survived up until week 3. Most plants in peat died in week 4 and 5, but P10 had less fatalities in the last week compared to the other two (Figure 2). Before succumbing, most plants in peat had signs of nutrient deficiencies, such as chlorosis and stunted growth.

The other groups and treatments had plants succumb to sudden wilting, causes unknown. Often only a singular plant in a pot was affected with the rest of the pot showing no signs of disease. Fungus gnat was a problem in the cultivation overall, but no clear signs of infestation between the groups could be observed. No signs of chlorosis were observed in any treatment in Compost and Mix.

3.3.2 Growth

Height was measured once a week, from the brim of the pot to the top of the highest plant. The final height showed no significant difference between the different treatments in compost and mixed treatment, *p*-value 0,474 and 0,219 respectively. Final height of plants within the pot varied (Figure 3).

Figure 3. Examples of Basil plants treated with peat, compost or a mixture of substrates.
From left to right: M5, M0, M10 and closeup of C0 showing example of one plant that didn't grow past the pot brim.

Figure 4. Selection of Basil plants grown in Peat.
Plants at harvest, left to right: P0, P5 and P10. All plants in P0 had died, P5 showed slight growth and P10 were just above the brim.

Because of the high mortality rates combined with the poor growth in Peat (Figure 4), no growth trajectory is made for this group. All treatments in Compost and Mix treatments followed the same trajectory over the five weeks (Figure 5 and Figure 6). Mix was slightly higher in week 3 but was caught up by Compost at harvest in week 5.

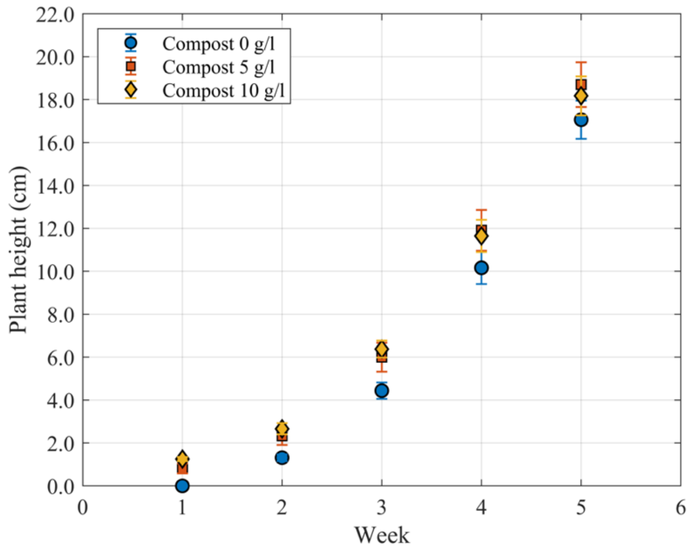

Figure 5. Weekly growth of Basil plants (cm) in Compost.
Each datapoint represents the mean value. All treatments follow the same trajectory of growth.

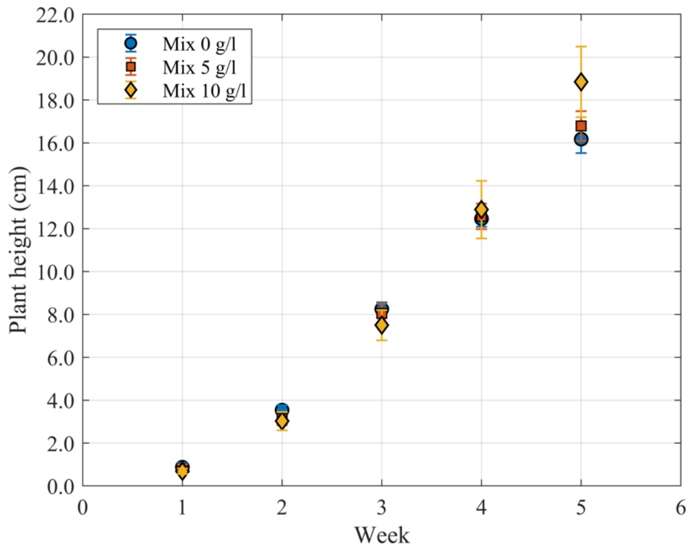

Figure 6. Weekly growth of Basil plants (cm) in Mixed substrate.
Each datapoint represents the mean value. All treatments follow the same trajectory of growth.

3.3.3 Yield

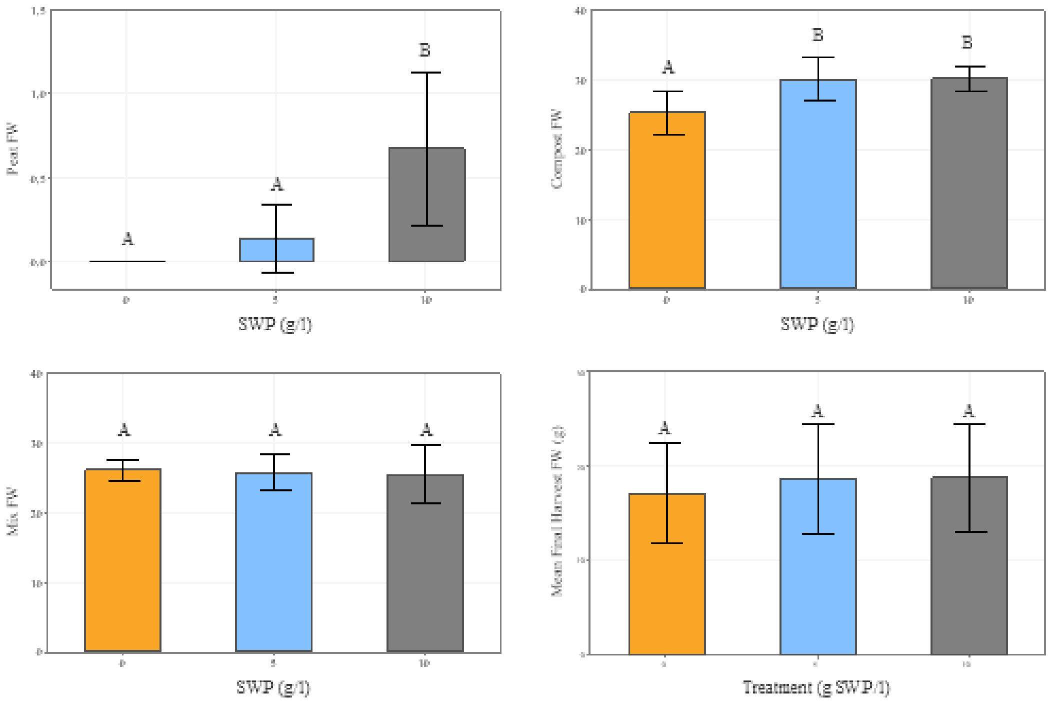

Figure 7. Fresh weight (peat, compost and mix) and total mean yield of Basil plants
All bars within each subplot that does not share the same letter are significantly different from each other (Tukey-test, P<0,05). Peat and Compost shows significant difference between the control and SWP treated containers. No difference in Mix and mean total harvest.

All plants were harvested at 60 days after sowing and 35 days after transplantation. Comparing the final total mean yield resulted in *p*-value 0,893, proving there were no significant difference between the different treatments when all samples of each treatment are pooled together (Figure 6). The peat group had a *p*-value of 0,002 indicating that there was a difference and Tukey (P<0,05) showed that the significant difference was between P10 and P5/P0. Compost had a *p*-value of 0,011 and the significant difference was found between C0 and C5/C10. Mix had *p*-value 0,942, no significant difference.

C0 had similar fresh weight (FW) mean as all the treatments in Mix (Table 7), but dry weight in mix were slightly higher when comparing treatments to their counterparts in Compost. Both C10 and P10 had a significant difference with P<0,01 when compared to control (Table 7).

Table 7. Mean, standard deviance (SD), dry weight and *p*-value of all treatments.

Treatment	Mean (g)	SD ±	Dry weight	*p*-value*
SWP0	17,17	12,62	9,0%	N/A
SWP5	18,69	13,79	9,0%	0,693
SWP10	18,83	13,59	8,7%	0,664
P5	0,13	0,243	9,7%	0,156
P10	0,67	0,544	9,3%	0,004
C0	25,36	3,8	7,9%	N/A
C5	30,17	3,75	8,1%	0,023
C10	30,25	2,171	8,3%	0,007
M0	26,16	1,802	9,9%	N/A
M5	25,77	3,05	10,1%	0,763
M10	25,56	4,9	9,2%	0,752

SWP is total of all groups. p-value is comparison between control (0 SWP) with 5 and 10 g SWP/l. P0 has no values as there were no surviving plants in that treatment.

4. Discussion

4.1 Characteristics

As with most organic fertilizers, sheep wool pellets are more than just a fertilizer as it comes with certain properties that alter characteristics in substrates and soil when added (Abbott et al. 2018). When deciding what amount of SWP to add in the substrate in order to achieve adequate fertilization, one needs to factor in the pros and cons of the physical properties of the pellets as well.

Preliminary tests were conducted to see the physical effects of different amounts of SWP. These experiments found that after watering, the substrates settled and the dissolved wool pellets moved to the top of the container, forming a thick mat which killed all plants. This was observed in containers with high wool/substrate ratio and the main cause of necrosis was suspected to be high salt levels. When growing from seed wool should not be spread on top of the substrate as the thick mat that is formed after watering most likely would prevent seedlings from breaking the surface, but if used when plants are already established the mat might reduce moisture loss. Making sure that the SWP wool/substrate ratio is not too high and that the pellets are placed deep enough and/or thoroughly mixed into the substrate would reduce the risk of 'wool-mat' formation. The final cultivation experiment followed the placement depth recommendation of 5 cm below the surface. This coincided with the plant depth when transplanting the basil, placing the plant roots in close contact with the SWP. Mixing the pellets with the substrate might be preferable as it spreads the fertilizer and reduces the risk of burning the plant roots. Reducing the amount of pellets that is exposed to air also reduces the loss of nitrogen in the form of ammonia gas. The smell of wool is also noticeably stronger when SWP is only spread on the substrate surface as opposed to pre-mixing them in the substrate, which might be a problem in closed greenhouse environments.

According to the preparatory characteristic tests, SWP has an expansion factor of 5. This affects the total substrate volume after watering which in can be both beneficial and problematic when dealing with container cultivation. When it comes to container cultivation SWP could potentially reduce bulk density of substrate and lessen the weight of each pot which in turn could affect handling and transportation costs. Abdallah et al. (2019) found that adding sheep wool to soil at a ratio of 2% significantly reduced bulk density and increased total porosity. Zheljazkov et al (2009) instead found that adding 2-14% wool to the growth medium did not significantly change bulk density or porosity. Further research is needed to determine if SWP would in fact change the properties of the substrates.

4.2 Cultivation experiment

All of the plants in P0 died and there was a significant difference in yield between the P5 and P10, but it is uncertain if it because of the nutrients from SWP alone. pH in the peat mixtures were 4.5 or below, making macro nutrient uptake difficult (Figure 7). The significant difference of yield was most likely a result of pH and not the breakdown of SWP. Peat had the highest levels of ammonia still in the substrate and several nutrients had higher final levels compared to the initial readings, indicating that the nutrient uptake was inhibited.

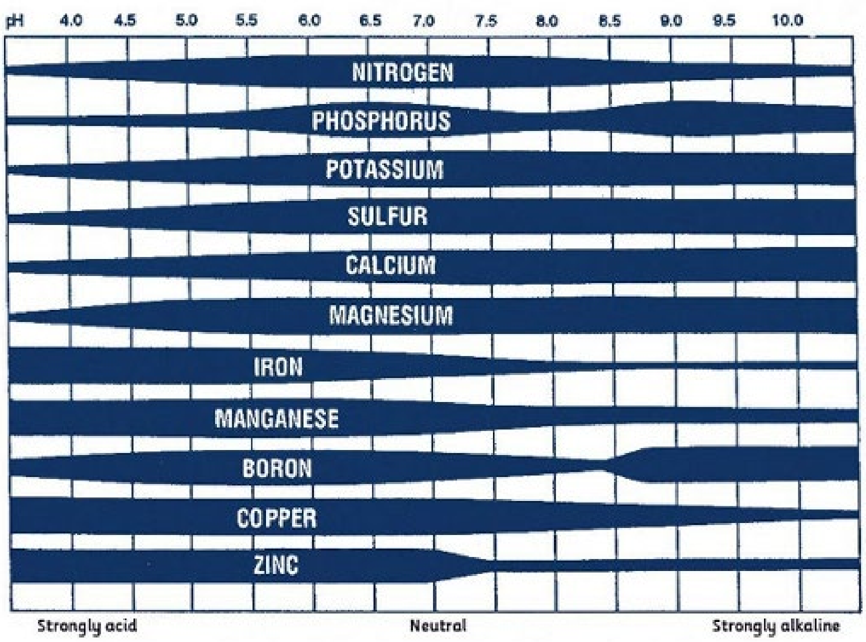

Figure 8. Effect of soil pH in plant nutrient uptake *(Silveira 2013).*

In the Compost group there was a difference between the control and the SWP treated containers but no significant difference between the two. This means that SWP did have an effect, but that 5 g/l would have been enough. All the compost group treatments had a pH 8.2, which is higher than the optimum for basil and in the range where phosphorous might be less available to plants (Figure 7). The reason why this group had significant difference in yield is uncertain but could be because compost has higher amounts of microbes that help with breaking down not only the compost itself but the SWP as well, increasing nutrient use efficiency (Xu et al. 2018).

There was no significant difference of yield between the treatments in the Mix group. pH was within the optimum range for basil plant nutrient uptake for both

M5 and M10 and slightly lower in M0, meaning that pH should not be the considered a damaging factor. It is uncertain what caused the significant difference of mortality within the group. Plants showed no signs of chlorosis but suddenly wilted, which could indicate over watering, fungus gnat infestation or nitrogen deficiency (Hale 2011).

The result of this experiment shows that when removing substrate as a factor there was no significant difference between the treatments, proving that SWP in dosages of 5 or 10 g/l does not affect the final yield in short duration container cultivation. While pH levels most likely have inhibited nutrient uptake in Peat and may have affected results in Compost, which had very low and very high pH respectively, there were no significant difference in the results of Mix where pH was at optimal levels. This indicates that 5 weeks is not enough time for the nutrients in sheep wool pellets to be released.

4.3 Future work

When mixing SWP with substrate it can be difficult to anticipate the final substrate volume of each pot. The current size of the pellets might be too big for smaller container cultivations. Smaller pellets or finely chopped wool would perhaps be better suited for a more homogenous spread in substrate mixes. Pellet sizes should be further evaluated in relation to the different needs of agriculture, horticulture, and forestry industries.

Sheep wool pellets has a NPK of 10-0,1-4,5 and its nutritional composition of both macro- and micronutrients indicated that it has a good potential to become a well-rounded fertilizer. Not seeing a significant effect from the added 5 and 10 g SWP/L could simply be because the dosage was wrong or due to issues of bioavailability. The recommended dosage of 5 g/L, approximately 0,5%, does not take in to account the substrates nutrient availability or the nutritional need of the crop. Zheljazkov et al. (2009) used different applications of uncomposted wool waste and found that at least 40 g wool per 0,85 l pot, approximately 2%, was enough to support 3-5 harvests of marketable yields during a cultivation period of around 250 days. Carlen et al (2020) found that more than 8% of sheep wool in a substrate caused salt damage and loss of yield. Further research is needed to determine the quantity of SWP that should be recommended for container cultivation. As mentioned earlier, this short project did not include a microbial analysis in relation to mineral nutrient bioavailability like nitrogen and phosphorus (Xu et al. 2018).

While the amount of SWP might have been too little, another way of looking at it is that there might have been too many plants. Ten plants per pot makes the drawdown of nutrients too rapid for most fertilizers to replenish. The volume of the pot could also restrict total growth and introduce unexpected complications not directly related to nutrition availability (Friesen 2021).

As 5 weeks was not enough to find evidence of SWP nutrient release, the question of when that occurs remains. Böhme (2018) grew tomatoes for 18 weeks and found no final significant differences between mineral fertilization and sheep wool pellets, but they did find that the containers with added sheep wool pellets had a higher fruit load at the end of the experiment, after approximately 10 weeks. To better understand when to add the pellets and what crops are best suited for SWP fertilization, further research is needed to find out more about when nutrient release occurs.

This experiment indicates that using sheep wool pellets in short cultivation container crops might require adding nutrients or having nutrient rich substrate mixes. Wool alone is not enough. With such low levels of phosphorous, SWP should be considered an incomplete fertilizer. In order to create an organic SWP-fertilizer more comparable to mineral fertilizer mixing other organic material such as sheep droppings with the wool could make it have a more immediate effect while simultaneously exploiting another nutrient source from sheep husbandry or elsewhere. German sheep producers have had positive results when mixing 70/30 wool and droppings (Gebendorfer 2020). The mixed pellets provided a higher level of phosphorus and magnesium and slightly lower nitrogen. Phosphorus levels in mixed pellets was 1 % in comparison to 0,15% in SWP, magnesium was 1,5 % compared to 0,05 % and nitrogen was 8,5 % compared to 10-12%. Similarly, Lal et al (2020) used composted waste wool in mixtures with sheep manure and crop residues in ratios of 30:50:20, showing significant improvements of soil health and crop production. Alternatively, one could consider mixing the SWP with other naturally available fertilizer product(s) (earthworms, seaweed extracts, insect frass) to achieve better matrix stabilization while enhancing the combined fertilizer efficiency (Lopes et al., 2022; Sani & Yong, 2022). Further research is needed to see what other organic materials could be mixed in with sheep wool to better suit short cultivation crops.

SWP has a high water holding capacity of 72% and a porosity of 61%, comparable to peat, which has 65% and 75%, respectively. As there is a need to reduce the amount of peat used in plant cultivation, SWP could substitute some of the peat that is added to soil mixtures to improve porosity and water retention. With an EC of 2,8 mS/cm and a pH of 8.3-8.6 in comparison to peat with 0,22 mS/cm and pH of 4.1, SWP should be considered a fertilizer first and a substrate amendment second. Perhaps that is not true for crops with short cultivation time, as there was little fertilizing effect for the first 5 weeks.

While no such observation was made in this experiment, SWP could be used to reduce the amount and frequency of watering. Ordiales et al (2016) found that sheep wool pellets can absorb water up to 3.5 times its own weight and when pellets are soaked the swelling effect provokes soil loosening and keeps ground moisture. Similarly, Lal et al (2020) used composted waste wool in outdoor barley container cultivation and found that there was a higher water use efficiency in pots containing waste wool. Abdallah et al (2019) found that despite a high water adsorbing capacity, sheep wool affected water movement in soil more than its water retention. Further investigation is needed to determine if and how much SWP affects water use efficiency in greenhouse container cultivation.

pH and other factors could have an impact of SWP nutrient release and further research is needed to determine what factors play a role in the breakdown and if SWP could be manipulated to better suit short cultivation crops. As nitrogen levels were low or almost depleted in all groups and treatments, special attention should be placed on the nitrification process.

5. Conclusion

The short-term indicated that sheep wool pellets (SWP) could not supply basil plants with the necessary amounts of nutrients. The levels of plant available nitrogen were almost depleted despite the fact that sheep wool contained relatively adequate amounts. This was indicative that nutrient release of SWP is probably too slow for it to be suitable to crops with a cultivation time of 5 weeks or less, at least with the quantities and amount of plants per pot that was tested.

SWP has physiological properties that could make it a beneficial substrate amendment by providing more air in the substrate and thereby reducing the amount and frequency of watering.

SWP has an NPK of 10-0,1-4,5 and the low levels of phosphorous made it an incomplete fertilizer. To work as full organic fertilizer with immediate effect, it needs to be mixed with, or accompanied by, additional organic materials. The better growth results in the compost substrate treatment were indicative of a plausible role of microbes in improving the bioavailability of nutrients.

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