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Growth media comparison for tomatoes in greenhouses

Prune Lacôte
Plant Sciences (Plant Production)

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Abstract

As part of the SiEUGreen project, development of urban farming has become of increasing importance as urban population and urbanization grow worldwide. Moreover, dealing with urban waste, and recycling of resources are critical for sustainability. Soilless plant production systems so far use mainly peat, of which the excavation is destructive to natural environment and a great source of greenhouse gas emission. The performance of two alternative growth media (GM) from different waste stream sources were tested on tomatoes variety 'Alicante' (in 2018), 'Golden Sunrise' (in 2018 and 2019) and 'Tastery' (in 2019). The locally sourced organic GM were kitchen waste based vermicompost, and biogas pig sludge digestate composted with garden waste. Moreover, a self-watering (SW) system was tested against a drip-irrigation (DI) system, for their suitability in the urban environment and for fruit quality parameters. The composts were both as performant as a peat-based media in term of yield production. A reduction of skin cracks in one the variety was found using SW compared to DI. Additionality, the media physico-chemical properties were reviewed.

Introduction

The Sino-European innovative green and smart cities (SiUEGreen) project is a cooperative multi-disciplinary development plan involving several European countries and China for greener cities (Jenssen et al. 2017). The key elements of the project are to assemble technologies to reach food security, resource efficiency and smart, resilient cities**.** Thus, one of the main objectives is the development of resource efficient systems for horticultural production in urban environments. This can be archived by investigating and developing urban agricultural systems in synergy with space utilization and local resources use. Urban agriculture is based on social, environmental and economical parameters. Adapted technologies must be developed meet those requirements and grow healthy nutritious food within the urban landscape.

A critical challenge to grow food in an urban environment is the access to quality substrate providing for plant growth. Soilless cultivation has become an increasingly popular practice due to its efficiency and practicality. It describes any methods of growing plant without the use of soil as a rooting medium (Savvas, Gianquinto et al. 2013). Commonly, the plant roots may grow either in a porous media or directly in a nutrient solution (Savvas, Gianquinto et al. 2013). The technique where plants growth is supported in aqueous solution is referred as hydroponics and is suitable for urban horticultural practices. Such systems applied to food crops reduces water needs, cultivation space, food health risks of products and of environmental contaminations (Schnitzler 2013). More specifically, aquaponics uses the hydroponics set up coupled with fish production. In such installation the fish feces are used for plant fertilization, the plant roots clean the water which is reintroduced in the fish tank. This closed system is particularly advantageous as it reduces plant root diseases and does not require nor mineral fertilization nor pesticides (Schnitzler 2013). As part of SiEUGreen, the method is aimed to be applied on rooftop greenhouse (Jenssen et al. 2017). Such setups may require specific installations and can be difficult to manage for the common gardener, since the balance of nutrients and wastes are crucial to success. And aiming for better space and waste utilization other technics and resources can be implemented.

Alternatively to hydroponics, plant can be grown in containers filled with substrate. This setup would be notably suitable for balcony gardens. However, containers-based soilless plant production can result in root health issues. A shallow layer of growing medium can quickly be saturated and water storage limited during irrigation (Barrett, Alexander et al. 2016). In this context, the media have the critical functions of anchoring the plant and efficiently supply of solutes, water and oxygen (Michel 2010). Therefore, the selection of a physically and nutritionally suitable media and of optimized irrigation techniques are crucial. Tomato is the most important vegetable crop grown worldwide. In Norway 12.8 metric tons of greenhouse tomatoes were produced in 2018 (FAOSTAT 2018). Its production, along of that of many horticultural crops for commercial or gardeners' purposes, so far use mainly peat-based substrates. Peat is easily available in the Northern hemisphere (Maher, Prasad et al. 2008) and require little treatment and inputs which makes it a relatively cheap and effective material (Barrett, Alexander et al. 2016). Its low pH is near the optimal for nutrients availability in a medium (Barrett, Alexander et al. 2016). Moreover, this naturally low pH of peats can be easily adjusted to desirable pH levels through the addition of lime, thereby, also adjusting Ca and Mg contents (Van Gerrewey, Ameloot et al. 2020). Moderately decomposed peats also have a high water capacity with simultaneously excellent aeration qualities (Schmilewski 2008). Those characteristics makes peats flexible and performant substrates. However, peat extraction is done by drainage and surface vegetation removal of peat bogs leading to irreversible damage to ecosystems in rare environments of high biological value (Alexander, Bragg et al. 2008). Additionally, peatlands are an important carbon sink but their exploitation releases stable, sequestered carbon into the active carbon cycle (Dunn and Freeman 2011). Indeed, peatland while globally covering only 3%, store about 30% of the global soil organic carbon pool on earth surface (Gorham 1991, Dunn and Freeman 2011). Thereby, CO_2 emissions from anthropologic peatland degradation were found higher than 10% of global emissions from fossil fuels (Parish, Sirin et al. 2008, Dunn and Freeman 2011).

While the selection of soilless growing media have been mostly based on their performance and economic cost, increasing emphasis is put on environmental criteria (Barrett, Alexander et al. 2016). Thereby, pressuring the growers to replace peat-based growth media (Schmilewski 2008).

A sustainable and economically competitive option to replace peat in urban agriculture is the use of more sustainable substrates based on industrial, agricultural and municipal organic waste resources. In organoponic systems, plant are grown in containers filled with organic substrates such as compost or other sources of organic matter (Orsini, Kahane et al. 2013). Thus, a growth media can originate from recycled organic wastes, garden waste, household waste, animal manure and human waste.

Conveniently, along with the growing interest for sustainable food production, efforts are made in waste management and sanitation. An example of such development is the use of organic material for biogas and heat production processing notably municipal wastewater as an energy supply. The Norwegian showcase of the SiEUGreen project is a building in construction (Jenssen et al. 2017) at Fredrikstad (Norway). It includes a water sanitation and organic waste recycling system that enable to collect and household notably brown water, faecal matter, for further production of biogas (methane) in a closed biogas reactor. In such systems, after the organic material has been turned into biogas, valuable nutrients are left in the digestate (Odlare, Arthurson et al. 2011). Thus, recycling of those left overs may have the potential to nourish food plants.

In conventional agriculture, digestates may be directly applied on a field and incorporated to enrich the soil (Odlare, Arthurson et al. 2011). However, is not possible to use it as a raw growth media on its own due to eventual phytotoxic levels of nutrients and unsuitable physical characteristics (Bustamante, Alburquerque et al. 2012). While some studies have investigated the possibilities to use municipal solid waste in mixture with peat (Herrera, Castillo et al. 2008) it can also be composted with other suitable waste. Notably, composted bark in mixtures can increase the air capacity, improve drainability, raise the cation exchange capacity and have a pH-buffering effect in a growth medium (Schmilewski 2008). More, specifically the use of vine shoot prunings as a bulking agent, in mixture with digestate for compost production, was found to produce a medium with suitable physico-chemical properties (Bustamante, Alburquerque et al. 2012).

Another composting technique is to use earthworms to degrade organic matter, thereby producing vermicompost. Vermicomposting involves the action of earthworms and bacteria in a biooxidation and stabilization process of the organic materials (Dominguez, Edwards et al. 1997, Hashemimajd, Kalbasi et al. 2004). (but does not undergo a thermophilic stage). It can be applied on manure (Dominguez, Edwards et al. 1997, Hashemimajd, Kalbasi et al. 2004) but commonly to kitchen wastes as well (Suthar and Singh 2008, Hanc and Pliva 2013).

Here, those waste management practices were used to grow tomato plants and asses of their potential to replace peat-based medias. A comparative study of three media was performed. First, a blend of vermicompost based on local food wastes and garden debris was used. It was made at Lindum AS in Drammen. Secondly, a digestate of pig sludge processed in a NIBIO biogas reactor was collected and composted with garden debris (finely chopped wood chips from apple trees mixed with a small amount leaf material) . The third media used was a peat-based substrate commonly used in horticulture (Tjerbo gartnerjord).
The main purpose of the experiment conducted, is to determine the potential of those alternative growth media sources for tomato production. Particular focus on the yield was emphasized along with fruit some quality parameters. Secondly, the physio-chemical properties and nutrient composition were investigated. Thirdly, self-watering containers was used to determine the water use over a growth period and the usefulness of free access to water to reduce the problem of cracked fruits experienced in the hot summer of 2018.

Abbreviations used:
DI = drip irrigation
SW = self-watering
LC = lindum compost
PC= pig manure compost
P = Peat media

Material & Methods

In 2018, a growth media experiment was conducted in SKP greenhouses, NMBU. Those data from 2018 were provided by Trine Hvoslef-Eide, department of plant biology and biotechnology, NMBU. The growth media tested were vermicompost and peat on two cultivars : 'Golden Sunrise' and 'Alicante'. Tomato plants were grown in 30L buckets in a room equipped with a drip irrigation system. A nursery room (H0619) at the Centre for Plant Research in Controlled Climate (SKP) at NMBU was used in that purpose. However, a large number of fruits harvested were cracked. To test weather this quality defect was related to the watering system or the growth media the experiment was reiterated in 2019. In that purpose pots disposing of a reservoir enabling for self-watering were tested against the 30L pots with DI used in 2018. Moreover, 'Alicante' was replaced by 'Tastery' and an additional growth media potentially suitable for an urban setup was tested. The 2019 experiment is described furtherly below.

Growth media

In 2018 and 2019 both a peat-mixture and vermicompost were compared.
Lindum is the commercial recycling plant of Drammen city where various types of compost are produced. One of their compost is a mixture particularly suitable for tomato. The blend is composed of household waste and vermicompost (a more detailed composition description could not be retrieved on time).
A peat mixture 'Gartnerjord' from Tjerbo was used. It is made of 86% sphagnum peat (low H-grade of 1-2), 10% sand and 4% granulated clay.
Pig manure digestate was collected from gas bioreactor at NMBU. 20L of it was mixed with 20kg of garden debris (small wood fragment, branches and dried leaves from apple trees). Two batches were made into plastic containers (Figure 1). First, collected waste product from the bioreactor was filtrated through a bedsheet to concentrate the organic matter. Then, garden debris and manure were thoroughly mixed for oxygenation. Afterward, the containers were left open in a warm place for about one month and a half. This was used only in the 2019 experiments.

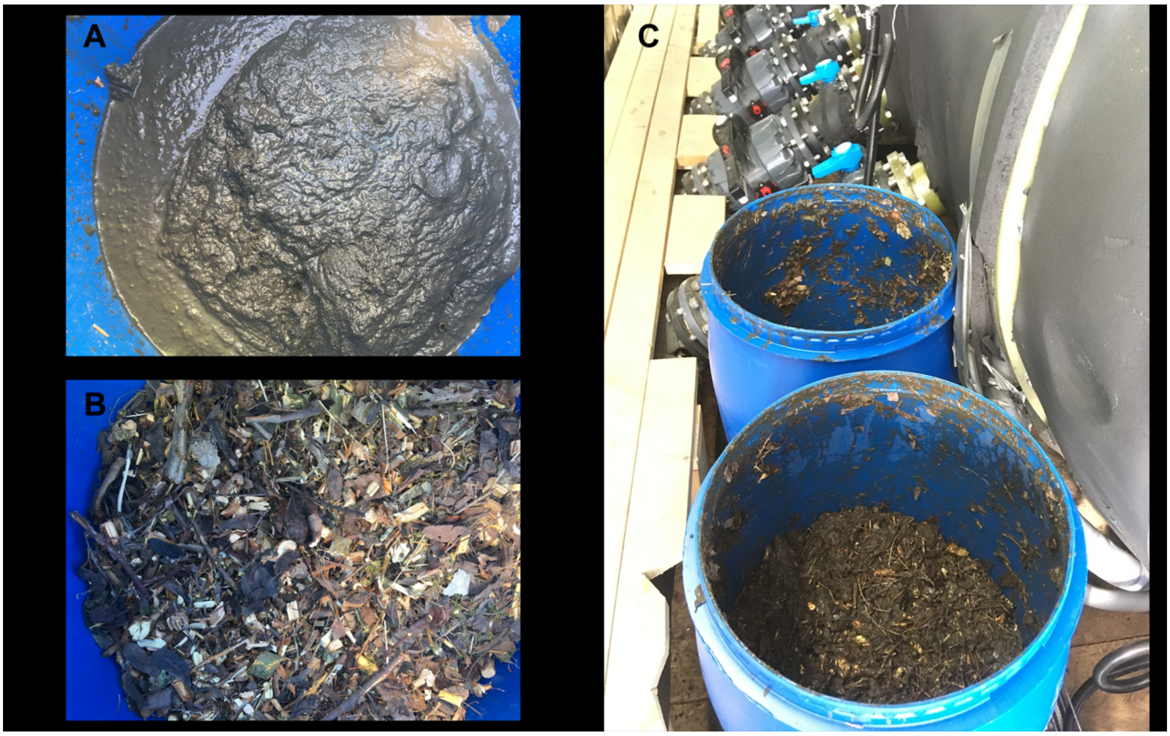


Figure 1 : Pig manure compost mixing process A : Sewage from gas bioreactor waste, B : Garden debris & C : sewage and garden debris mixed in the open air before put up in two containers and stored aside in the bioreactor shed.

Experimental set up

The experiment was set up the 24th of May 2019. Tomato seeds of two varieties, 'Tastery' and 'Golden Sunrise', were sown in peat on the 6th of April 2019. Following this, plants were transplanted into 12cm pots after 2 weeks and in 4L pots on the 6th of May for the plants 'Golden Sunrise' and on the 25th for the plants 'Tastery'.

A second batch of 'Golden Sunrise' was sown directly in 12cm pots on the 6th of May due to low germination rates of the first batch. Those were transplanted the 6th of June, and concern the treatment in Pig manure Compost in SW and the treatment in Lindum 'torv fri gartnerjord' in DI (Figure 2)

Two nursery rooms (H0608 and H0619) at the Centre for Plant Research in Controlled Climate (SKP) at NMBU were used for the experiment. One room was equipped with 30-liter containers with drilled holes in the bottom and drip irrigation installed in each container. The other room had self-watering containers (18L growth medium per plant) with water/nutrient reservoir (9 L per plant) from Plastia. In the first, four treatment were applied in 5 replicates, in the second, five treatments made in 4 replicates (Figure 2). Twenty plants grew in each room. Plants were transplanted from peat 4L pots.

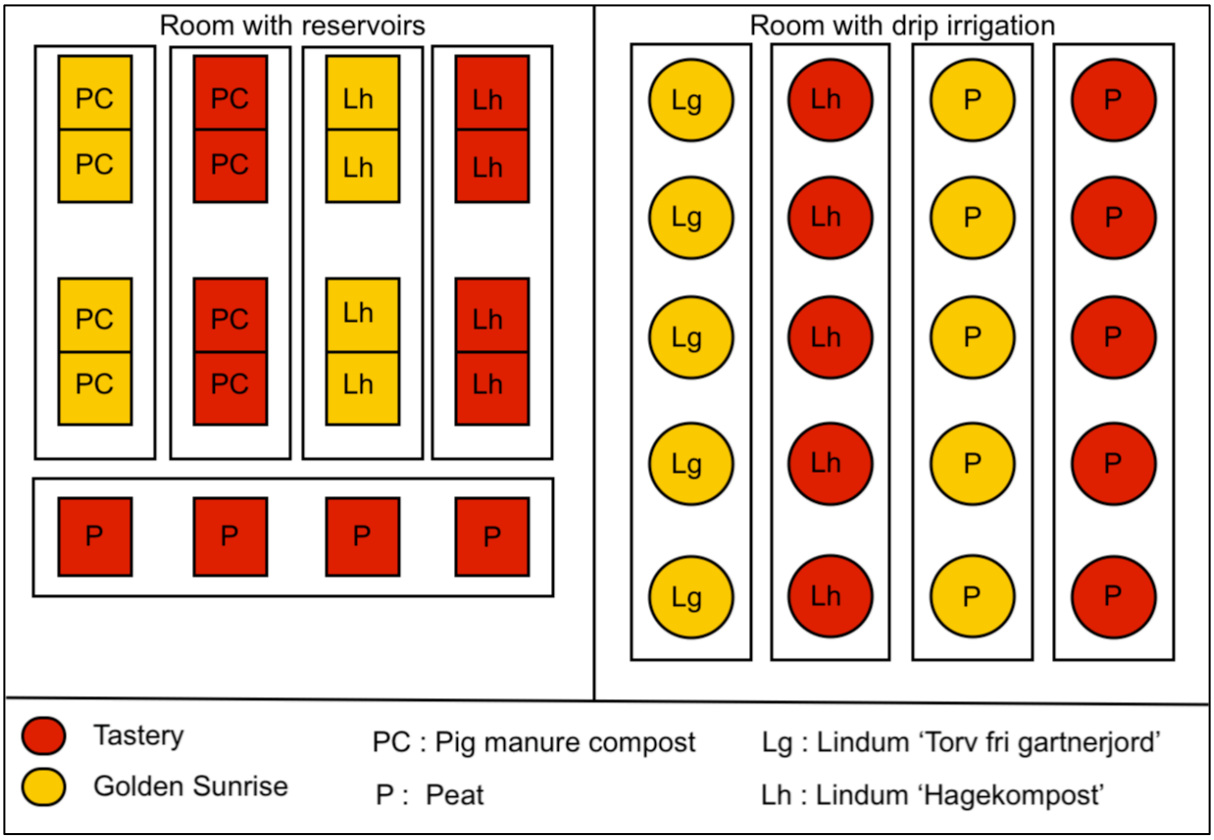


Figure 2 : Schematic map-overview of the experimental set up across both rooms

The plant stems were attached and rolled to a string hang to the celling. Throughout the growing season, as the plant got taller, the strings were gradually let looser and thereby lowering the plant making fruit accessible at harvest and enabling optimal growth.

Treatments in drip irrigation

Plants were transplanted into 30L round buckets. Drip irrigation was set gradually, and by the beginning of the harvest, each pot contained 3 tubes. Watering occurred 4 times a day, at 6 am, 12 pm, 17 pm and 21 pm for 5min. Overall, each plant was provided with 2,8L nutritionally enriched water every day.

Treatments in reservoirs

Pots with reservoir (Figure 3) were either double (Berberis duo) where two flower boxes shared a 18L reservoir either single equipped with 9L water capacity. The flower boxes of both double and single had an 18L substrate capacity. The reservoirs were regularly filled up before reaching down the minimum water level mark and the volume of nutrition water added was measured.

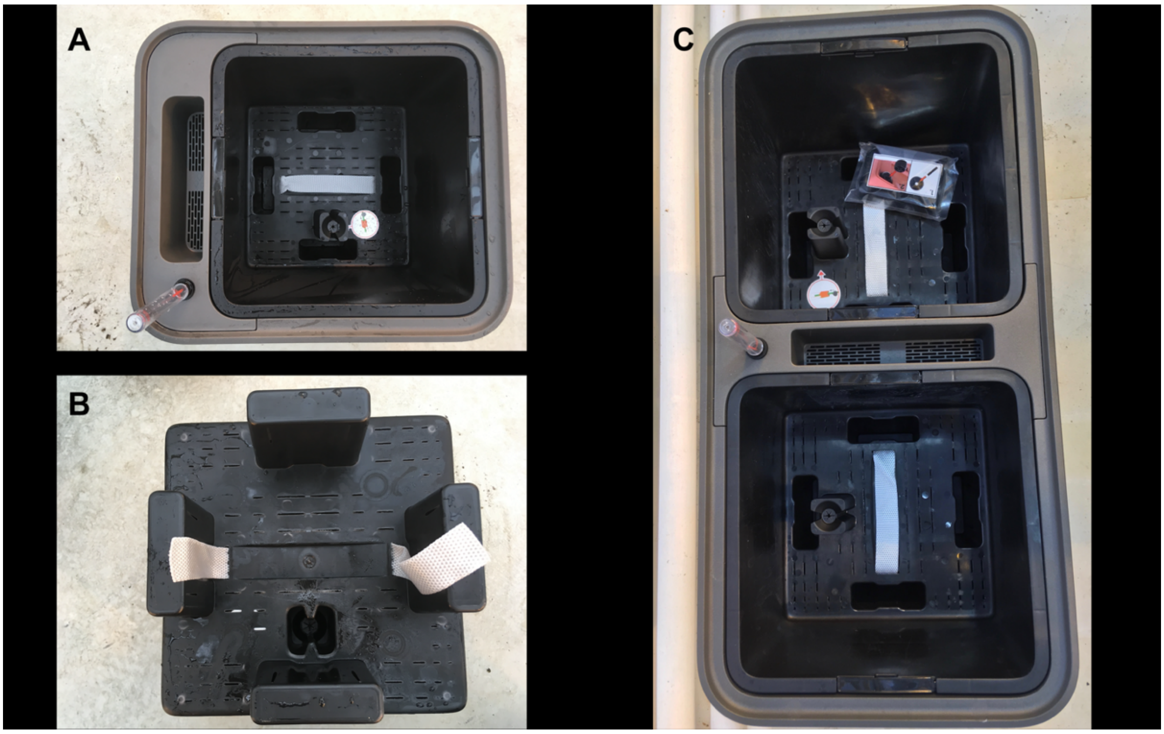


Figure 3 : Reservoir pots A : single seen from above, B : Flower box seen from the underside with straps reaching the water tank, C : double pots seen from above.

The nutrition water composition is display in Table 1 below. The analysis was performed by Eurofins Agro (Moss, Norway). The same solution was used to water end fertilize the plants in 2018.

Table 1 : Nutritionally enriched water composition

	Cations ppm (mg/L)					
pH	NH4	NH4-N	K	Na	Ca	Mg
6	7,2	5,6	129	28	108	22
	Anions ppm (mg/L)					
EC (mS/cm) 25°C	NO3	NO3-N	Cl	S	HCO3	P
1,4	515	116	35	42	12	27
	micro-nutrients ppb (µg/L)					
Si ppm (mg/L)	Fe	Mn	Zn	B	Cu	Mo
2,8	1117	346	176	173	57	48

Pig compost treatment

Fifteen liters of manure per plants were used only in reservoir pots, as the PC was very coarse, 1L of peat was added at the top of the pot. In total 120 L of pig manure compost was used for 8 plants.

Yield component measurement

Fruits were harvested 3 times a week. For 'Tastery' the whole raceme was weighted, while the weights of single fruits of 'Golden Sunrise' was measured. The fruits harvested and the portion of those presenting physical quality defects such as skin cracks were counted.

Soil physico-chemical properties analysis

Two samples of each growth media were taken at the beginning of the experiment and each were divided in two replicates. Only the Lindum compost 'Torv fri gartner jord' was not send for analysis as it was received later. The soil analysis was performed by the Soil and water chemistry laboratory (IMV), Jordfag, NMBU.

Data analysis

The data collected across the experiments were handled in Excel program. Statistical analysis and plots displaying those were constructed in R studio.

Equations used for data transformation

Cumulated yields were calculated by assigning, at a day x, the sum of all previous harvest included its own. In order to compare production and quality defect among all treatments standardized yield averages were calculated. The equations used for this are displayed below.

- $\text{Average number of fruit per day} = \frac{\text{Total number of fruits harvested}}{\text{Number of days}}$
- $\text{Average weight per day} = \frac{\text{Total weight harvested}}{\text{Number of days}}$

The 'number of days', based on the first harvest to the end of experiment, was of 50 for experiments in 2018, 51 for those of 2019 except for that of 'Golden Sunrise' in LC & DI and in PC & SW. Those were transplanted later leading to retarded fruiting compared to other treatments. Therefore, for these treatments the 'number of days' was adjusted to 34 days.

- $\text{Ratio of cracked fruit} = \frac{\text{Number of cracked fruits}}{\text{Total number of fruits harvested}} * 100$

Statistical validation

Group differences significance were calculated through a Tukey Post Hoc Honestly significant difference (HSD) test using the function HSD.test ('agricolae' package) based on an ANOVA in R studio. Alternatively, a t-test based mean comparison was applied to the ratio of crack fruit comparison between watering systems. The data and R code templates used are provided in annex.

Results

Yield

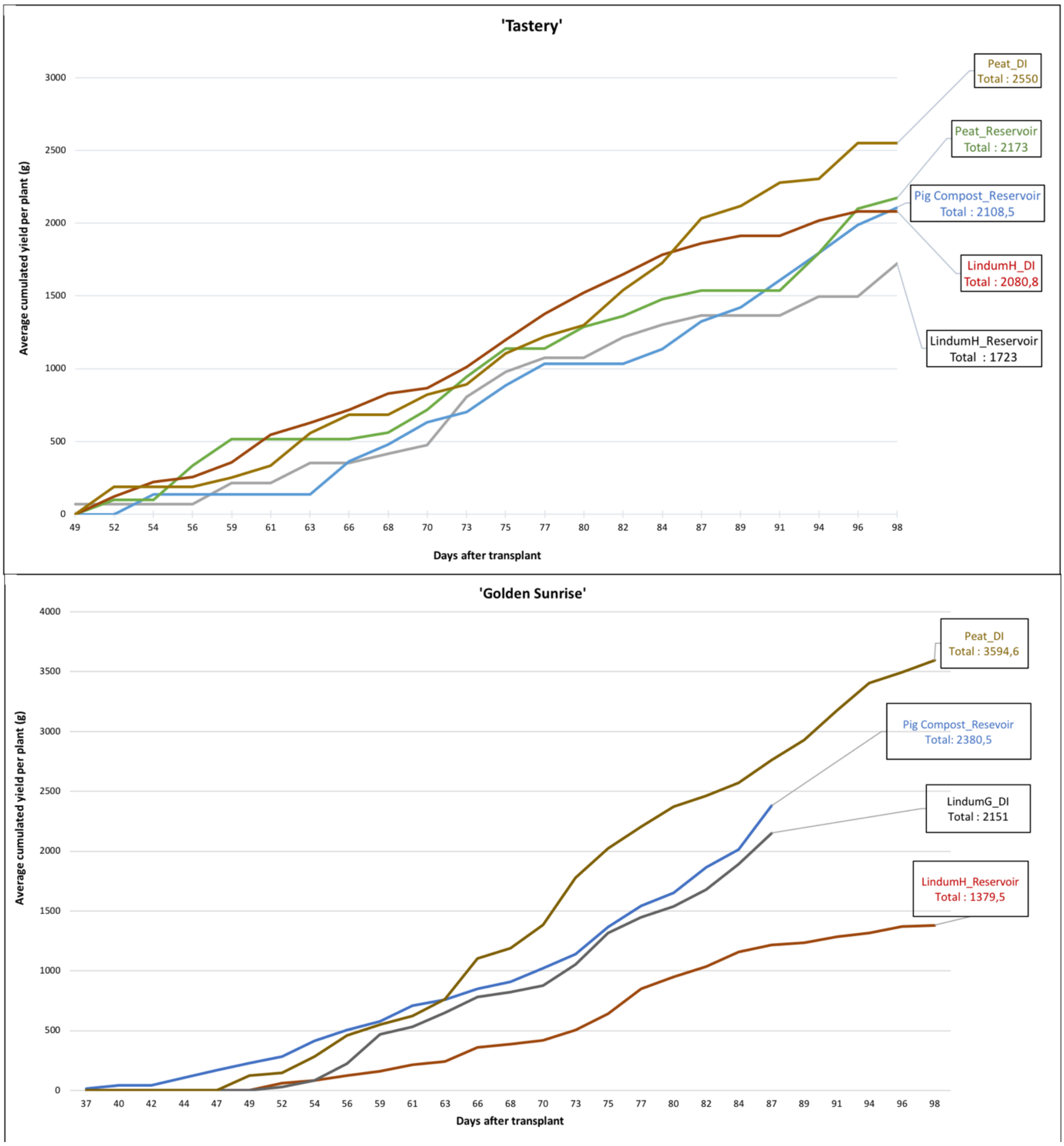


Figure 4: Average cumulated yields in grams of fruits harvested of 'Tastery' and 'Golden Sunrise' plants over the growing season per treatment indicated by the labels with first growth media type (Peat, Pig manure Compost, LindumH = 'hage kompost' and LindumG ='gartnerjord'), the watering system (DI = Drip Irrigation and Reservoir = self-watering system) and Total = total yield produced after final harvest. Data from 2019 only.

For both 'Golden Sunrise' and 'Tastery' peat outcompeted respectively PC and LC at 98 days after transplant (Figure 4). However, the curves evolutions display rather important variation from one harvest to the other in 'Tastery' (Figure 4). With time, the yield gap between treatment got up to 827 grams for 'Tastery' and 2215 grams for 'Golden Sunrise' plants.

However, statistical analysis did not reveal significant differences in yields based on the growth media for both variety regardless of the watering system used (Figure 5).

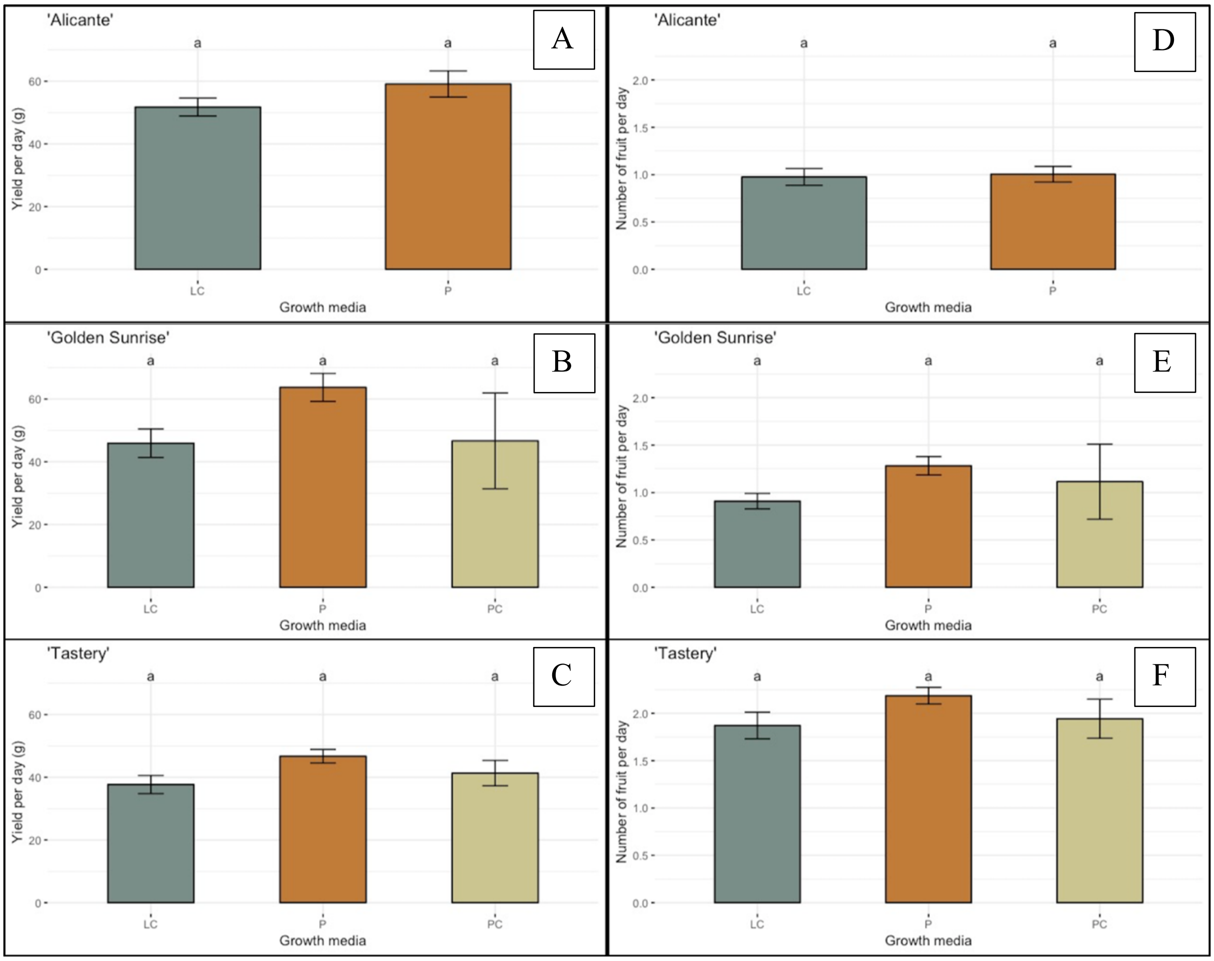


Figure 5 : Average fruit yield in grams (A,B &C) and number of fruit (D,E &F) produced per day for 'Alicante' (A&D), 'Golden Sunrise' (B&E) and 'Tastery' (C&F) depending on the growth media (LC = Lindum Compost, P = Peat and PC = Pig manure Compost). Letters indicate difference significance at 0,05 level of significance, whisker correspond to the standard error. Data for 'Alicante' were collected only in 2018, 'Golden Sunrise' in 2018 & 2019 and 'Tastery' in 2019 only.

Both yield and fruit production differences between treatments were found insignificant among all varieties (Figure 5). Despite this, it can be noticed that LC yielded slightly less fruits in terms of weight and number on all varieties, than that of P and PC. Meanwhile, on average PC also seemed to yield less than peat, the trend is less clear but the standard error shows great variation, so no significant differences can be demonstrated.

Cracked fruits

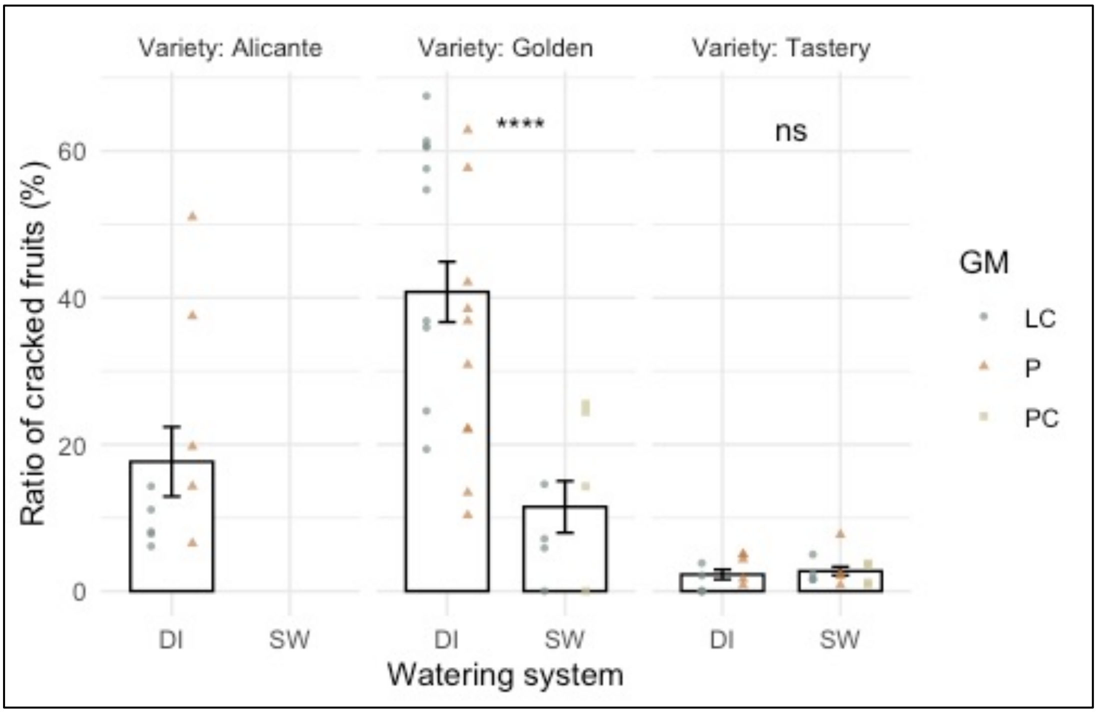


*Figure 6 : Occurrence of cracked tomato fruit (%) depending on the watering system (DI = drip Irrigation and SW = self watering) with points indicating the ratio of cracked fruits depending on the growth media (LC = Lindum Compost, P = Peat and PC = P Pig manure Compost). Whisker correspond to the standard error, mean comparison (t.test) depending on the watering system, p-value significance levels *** = <0.001, ** = <0,01, * = <0,5, ns = > 0.5.Data for 'Alicante' were collected only in 2018, 'Golden Sunrise' in 2018 & 2019 and 'Tastery' in 2019 only.*

'Golden Sunrise' fruits were found globally to crack more easily than the two other varieties Figure 6. The ratio of cracks 'Golden Sunrise' fruits was significantly greater with the drip irrigation system with on average less than half the number of cracks in SW. In 'Tastery', crack fruit did not occur differentially with one irrigation system or the other, nor depending on the growth media. Moreover, the variety had a lower ratio of such quality defects than the other varieties. 'Alicante' were grown only in 2018 with drip irrigation. Figure 6 shows a great difference in term a ratio of cracked fruit between peat and LC for this variety. However, that difference was not found to be significant (Figure 7). The growth media was not found as a significant factor of cracks in other varieties either. Moreover, while here the peat seemed to have a greater share of cracked fruits than LC for Alicante, the reverse phenomena was seen in 'Golden Sunrise' with DI (Figure 6).

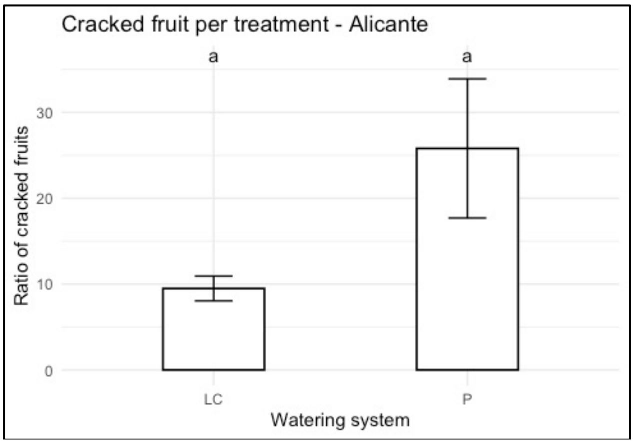


Figure 7 : Ratio of cracked fruit (%) of 'Alicante' depending on the growth media (LC = Lindum Compost, P = Peat). Letters indicate difference significance at 0,05 level of significance, whisker correspond to the standard error. Data from 2018.

Water Consumption

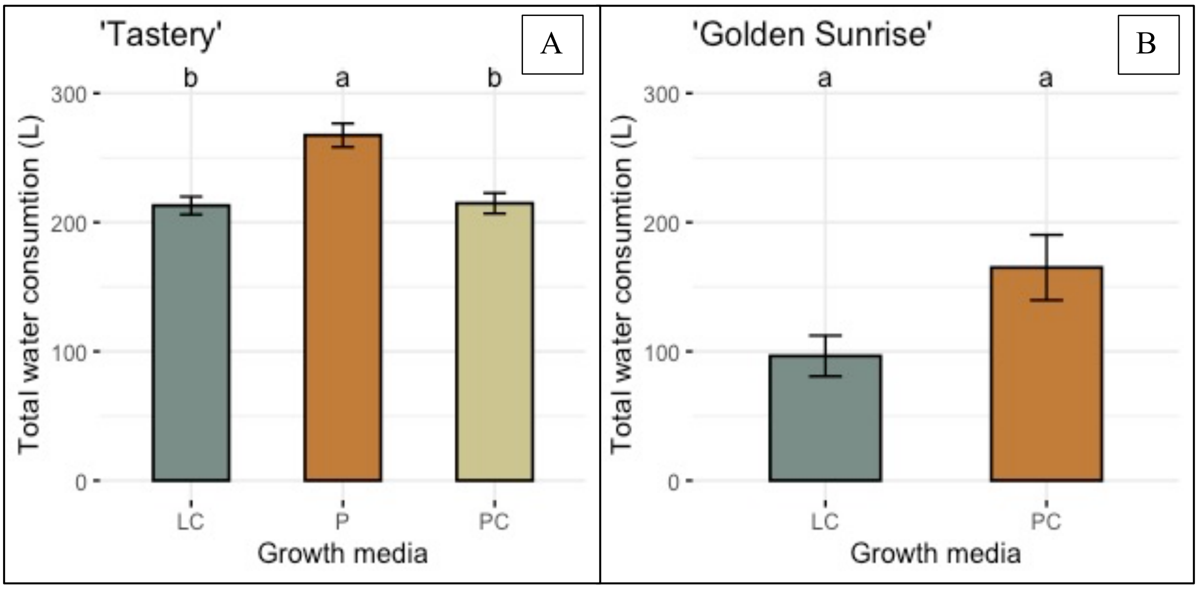


Figure 8 : Total fertilized water consumption in SW treatments in liters for A : 'Tastery' and B : 'Golden Sunrise' depending on the growth media (LC = Lindum Compost, P = Peat and PC = Pig manure Compost). Letters indicate difference significance at 0,05 level of significance, whisker correspond to the standard error. Data from 2019.

In the DI treatment, the amount of fertilized water added reached 270 litters over the same period of time. The maximum water received in SW was an average of 267 liters for 'Tastery' in P. The 'Tastery' grown in LC and PC received a significantly lower volume than P (Figure 8). 'Golden Sunrise' plants in LC as in PC consumed less than 'Tastery'. In LC, 'Golden Sunrise' seemed to have had less solution than in PC but insignificantly.

Soils physico-chemical properties

Physical properties

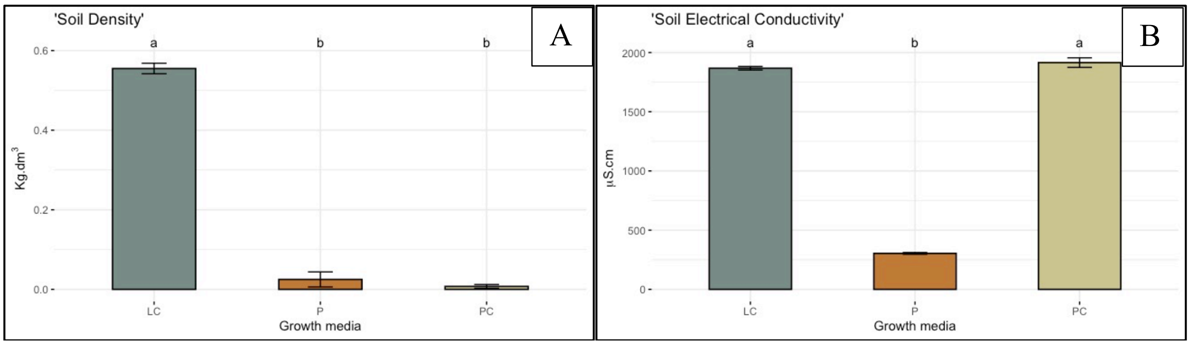
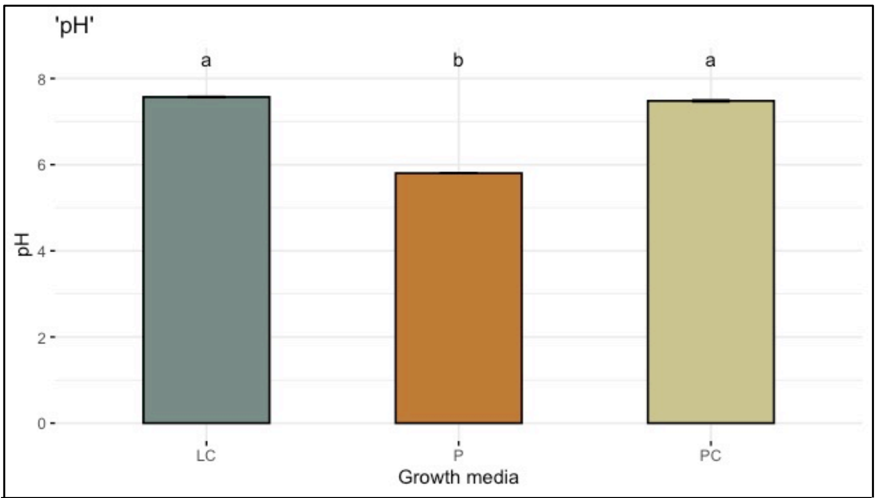


Figure 9 : Density in kg per dm3 and Soil electrical conductivity in µS per cm of each growth media(LC = Lindum Compost, P = Peat and PC = Pig manure Compost), letters indicate difference significance at alpha = 0,001, whisker correspond to the standard error. Data from 2019 experiments.

The density of peat and PC was not found significantly different averaging below 0,1 $kg.dm^3$ while the mean density of LC reached about 0,5 $kg.dm^3$ which is significantly higher than peat and PC (Figure 9, A). The composts were found significantly more conductive than peat but very similar to one another as depicted in (Figure 9, B) .

Soil pH



GM	pH
P	5,80
LC	7,57
PC	7,48

Figure 10 : Average pH of each growth medium (LC = Lindum Compost, P = Peat and PC = Pig manure Compost), letters indicate difference significance at alpha = 0,001, whisker correspond to the standard error. Values displayed in table are the average pH of each growth media. Data from 2019 experiments.

The composts pH were very similar to one another and significantly more basic than that of the peat soil but remaining in a good range for tomato growth (Figure 10).

Dry Matter and SOM (LOI)

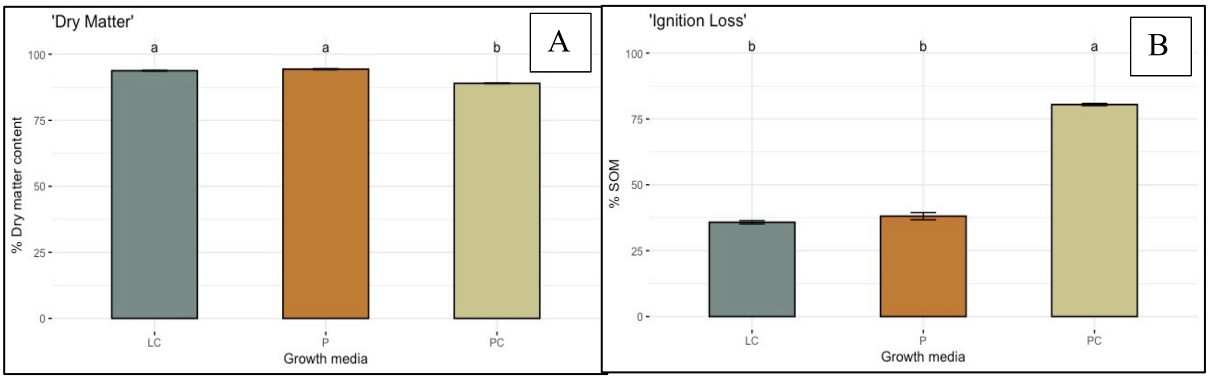


Figure 11 : Average percentage of A: dry matter and of B : soil organic matter (SOM) in each growth (LC = Lindum Compost, P = Peat and PC = Pig manure Compost), letters indicate difference significance at alpha = 0,001, whisker correspond to the standard error.. Data from 2019 experiments.

Regarding the dry matter content and soil organic matter (SOM) content, LC and peat were found to share same amounts, in an other hand, PC was lower in dry matter and has a higher percentage of SOM (Figure 11).

Soil Macronutrients

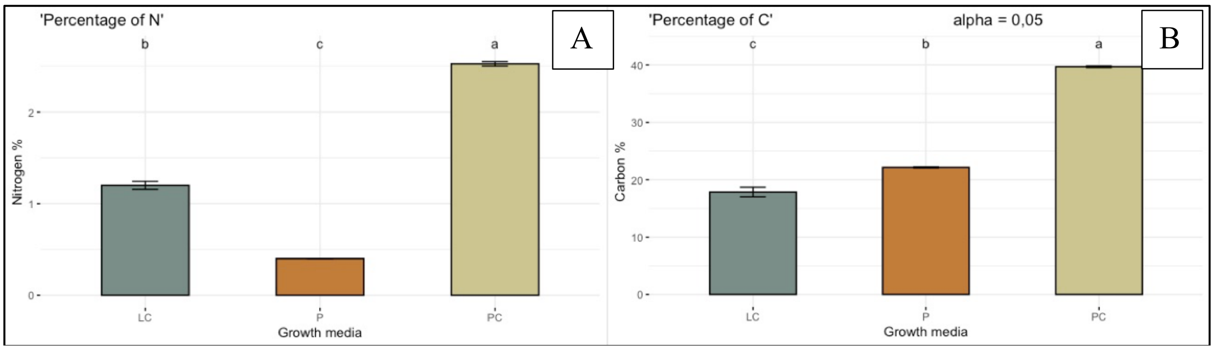


Figure 12 : Average percentage of Nitrogen and Carbon measured in ecah growth media with with LC = Lindum compost, P = Peat, PC = Pig manure compost, letters indicate difference significance at alpha = 0,001 for Nitrogen and 0,05 for Carbon, whisker correspond to the standard error. Data from 2019 experiments.

The composts were found with a higher percentage of N than peat (Figure 12, A), especially PC of which the NO3 content was greater than that of both other media tested (Figure 14). Meanwhile, peat was the media with the greatest amount of NH4. All in all, the three soil were richer in NO3 than NH4. However, while the content in NO3 was about 5,5 and 2,7-fold higher respectively in PC and P than that of NH4, LC was found with a more balanced proportion of both N forms and that with only 1,7 fold higher NO3 content. The C and N fraction in peat was notably dominated by C, with the lowest percentage of N (Figure 12, A) and the highest C/N ratio of the three media (Figure 13). The C/N ratio of both composts was found very similar with no significant difference.

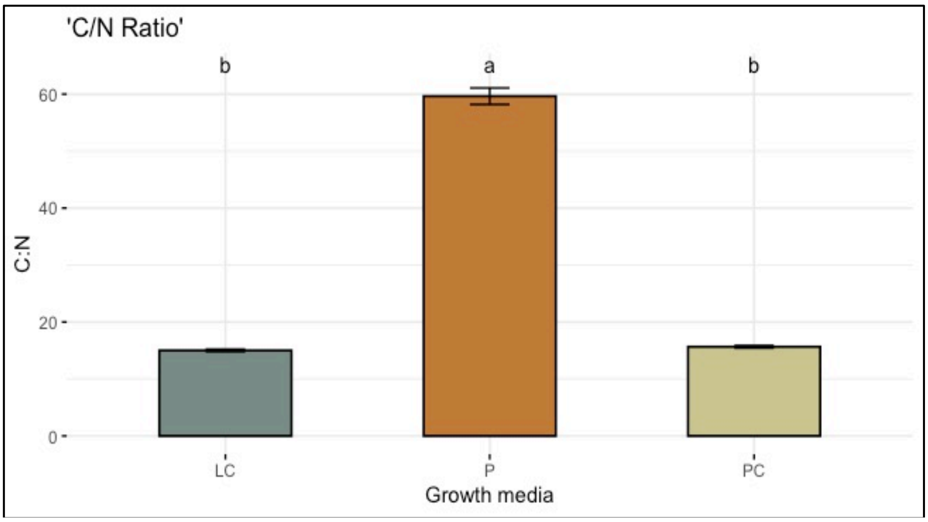
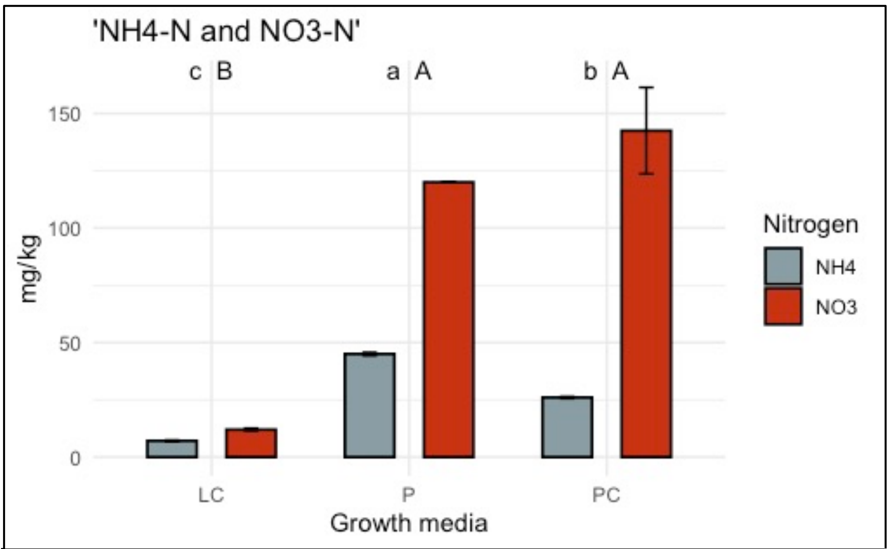


Figure 13 : Average Carbon/Nitrogen ratio in each growth media with LC = Lindum compost, P = Peat, PC = Pig manure compost, letters indicate difference significance at alpha = 0,001, whisker correspond to the standard error. Data from 2019 experiments.



GM	**NO3-N** (mg/kg)	**NH4-N** (mg/kg)
P	120,00	45,00
LC	12,00	7,08
PC	114,00	20,80

Figure 14 : Ammonia (NH4-N) and Nitrate (NO3-N) content in mg per kg of each growth media with LC = Lindum compost, P = Peat, PC = Pig manure compost, lower case letters indicate difference significance in ammonia content and upper case letters in nitrate content between growth media at alpha = 0,001, whisker correspond to the standard error. Values displayed in table are the average content of each growth media. Data from 2019 experiments.

For the rest of the macronutrients measured here, the composts had higher content in P, Mg, Ca, K and S (Figure 15). The content in phosphorous of PC was especially high, reaching up 9,85 g/kg of material (Figure 15, A). It also contained the highest content of S (Figure 15, E), while LC had a greater content of Mg (Figure 15, B).

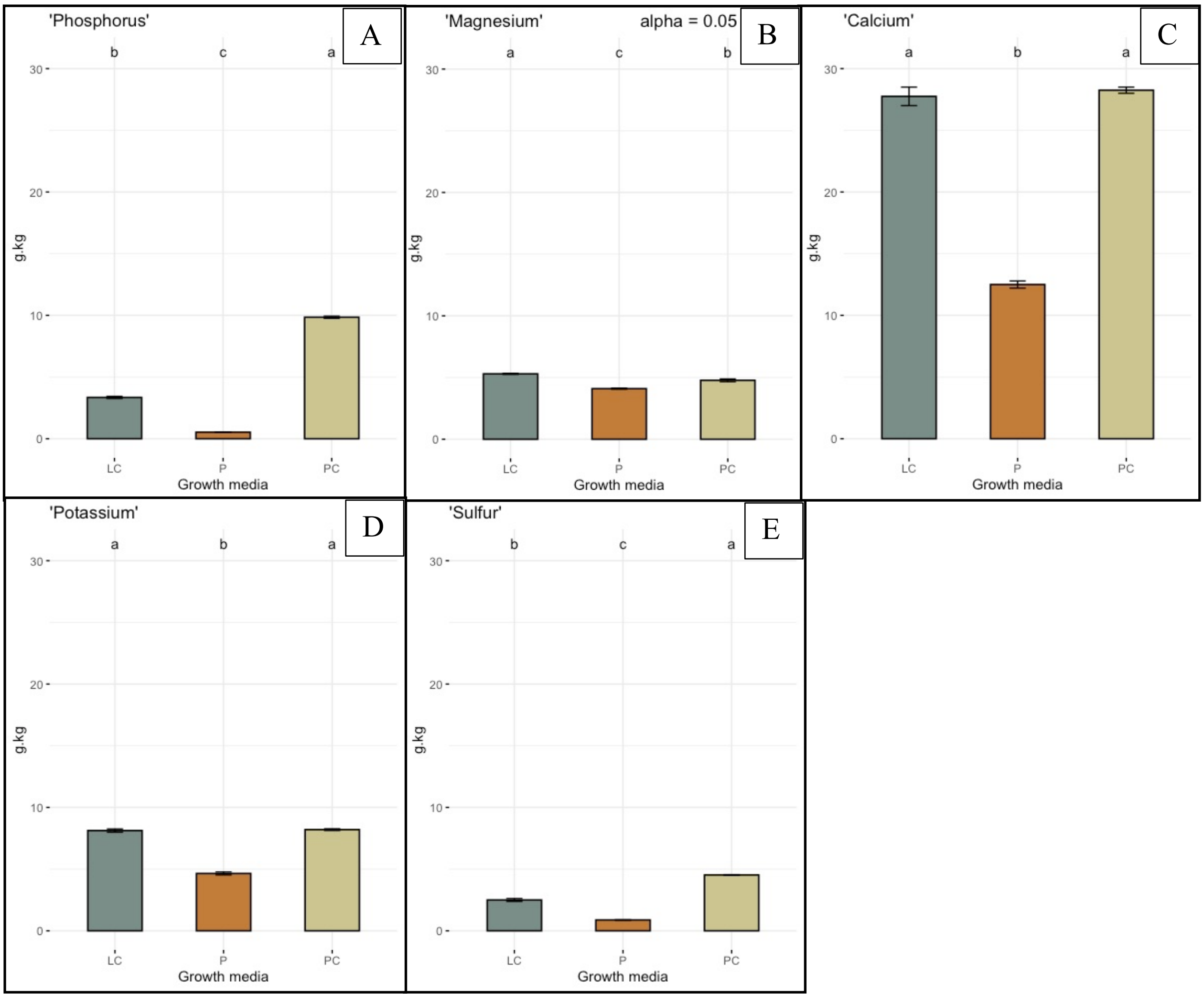


Figure 15 : Average A: Phosphorus, B: Magnesium, C : Calcium and D : Potassium and E : Sulufur content in g per kg of each growth media with LC = Lindum compost, P = Peat, PC = Pig manure compost, letters indicate difference significance at alpha = 0,001 except if stated otherwise above the individual plot, whisker correspond to the standard error. Data from 2019.

Soil Micronutrients

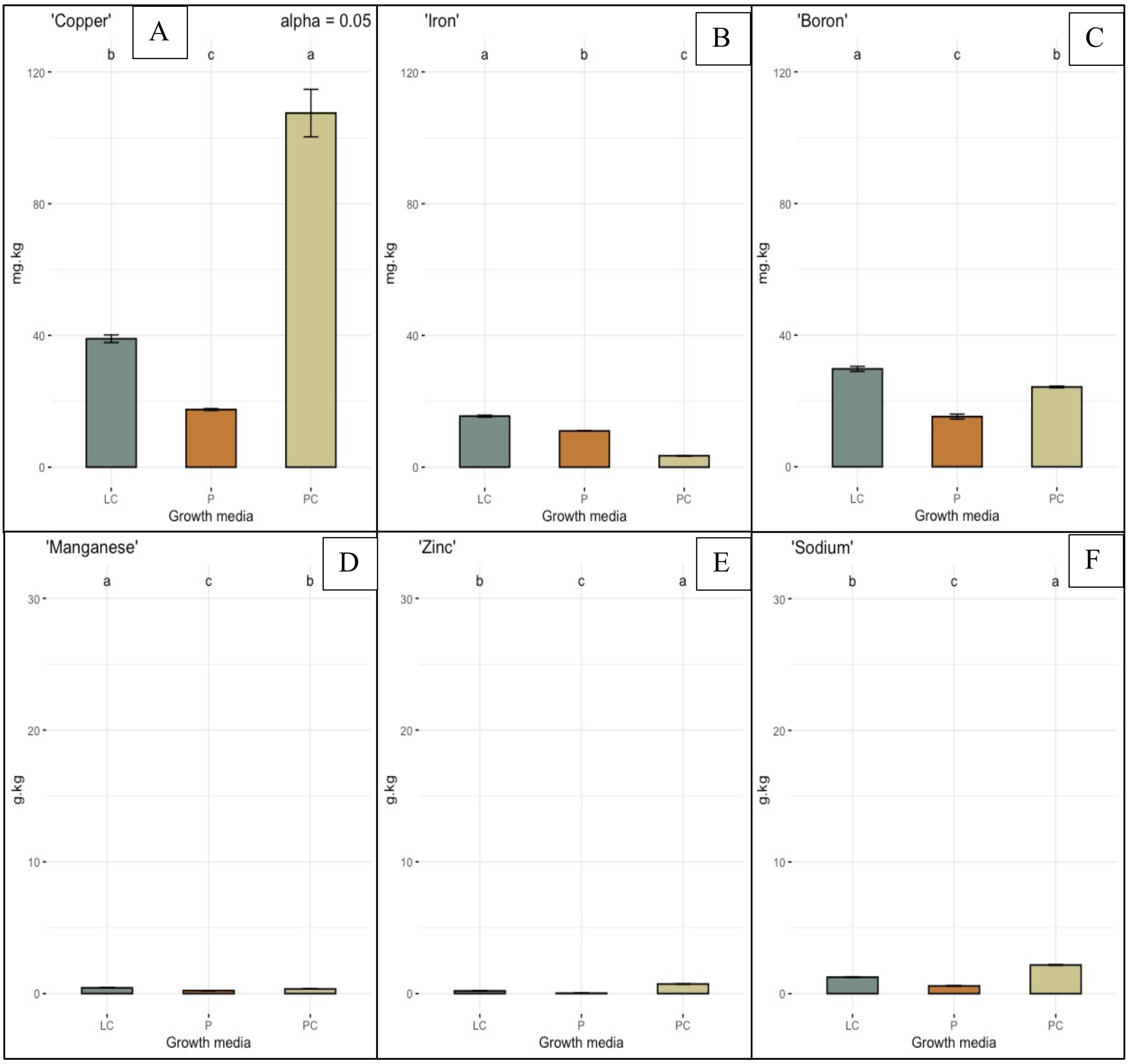


Figure 16 : Average A : Copper, B : Iron and C : Boron in mg/kg and D : Manganese, E :Zinc and F :Sodium in g/mg of each growth media with LC = Lindum compost, P = Peat, PC = Pig manure compost, letters indicate difference significance at alpha = 0,001 except if stated otherwise above the individual plot, whisker correspond to the standard error. Data from 2019.

The composts were found with higher micro nutrient than P, except for iron which was significantly higher in peat than in PC, but in greatest amount in LC (Figure 16, B). LC also had higher contents of B and Mn (Figure 16, C&D). Meanwhile, PC was found especially rich in Cu, Zn and Na compared to the other media (Figure16, A, E &F).

Discussion

Ensuring environmental sustainability of food production in an urban environment has great potential. Innovations in the field of recycling are expanding. The suitability and performance of recycling products remains to be assessed for vegetable crops productions. Both Vermicompost and digestate-based compost were found suitable to sustain tomato plants. The yield of tomato plants grown in those media, in term of production weight and number of fruits, has been found to compete with the performance of peat in three different varieties. The 'Golden Sunrise' in LC and SW were found with the lower total yield (Figure 4). Those treatments were placed on the hallway side of the room (Figure 2) and have been shaded which is likely to have impacted the yields. Especially concerning the 'Golden Sunrise' which were smaller than 'Tastery'. Globally, the in SW the plant tended to yield less than in DI for the same type of GM (Figure 2), this was not tested statistically. However, it could be speculated that the possible reasons for this trend was the lower amount of substrate and space available to the roots in the flower boxes of the SW system than that of the DI system (respectively 18L and 30L capacity) and the lower volume of nutrient solution received in the composts treatments. Those reasons are also likely to be linked to one another. The 'Golden Sunrise' in PC were found to yield fruit more quickly after transplant than the other treatments. Despite the fact that the average yield of this treatment nor that of 'Tastery' in PC was not found significantly greater than the others, this could be due to the high quantity available nutrients in PC at an early growth stage. The large variations in yield found in PC notably for 'Golden Sunrise' is difficult to explain, it is possible that some plants got shaded by others as in this treatment plants were transplanted later.

In the experiment of 2018, tomato fruits from the variety ‘Alicante’ and ‘Golden Sunrise’ were found prone to cracking in a DI system. In order to eventually remediate to this issue and furtherly investigate the potential effect of the GM selection on this, a SW system was included in 2019. The different GM were not found to affect the ratio of cracked fruit in the harvest. Whereas the watering system was found to be a great factor affecting this phenomenon. With a substantially higher ratio of cracked ‘Golden Sunrise’ in DI. Indeed, irregular watering leading to variation in from low to high soil moisture is well known to affect skin strength and cause cracking during tomato fruits growth (Peet 1992). However, other factors, both environmental and genetic are known affect skin cracks occurrence. Notably, common explanations are relative humidity, temperature and irradiance as well as an increased growth rate which may be the results of the previously stated environmental factors (Peet 1992).

‘Tastery’ fruits were not found susceptible to the irrigation system. A study of the impact of fruit ripening outlined the importance of the developmental rate between the breaker stage (10% of the fruit is red) and overripe in cuticles cracks in cherry tomatoes.(Domínguez, Fernández et al. 2012). This was found to occur predominantly on fruit ripening on the vine compared to that harvested early. In ‘Tastery’, the whole raceme was harvested at once while ripening occurred differentially from top to bottom. Therefore, a late harvest timing might have contributed to cracks on the fruit at the top of the raceme ripening earlier. The selection of the racemes to be harvested earlier ripening stage could have reduced the overall ratio of cracked fruits in that variety.

Finally, regarding the higher ratio of fruit cracks of ‘Alicante’ grown in P compared to that of LC in 2018, despite insignificant, those results could have been the consequence of the lower electrical conductivity of P. Indeed, (Dorai, Papadopoulos et al. 2001) reported a study in which an increased electrical conductivity reduced greatly the incidence of fruit cracking.

The electrical conductivity is a measure of the salinity, thus of the amount of dissolved nutrients. This was found higher in composts than in P due to their, globally, greater nutrient content. While electrical conductivity above 2.3–5.1 mS/cm can potentially reduce the yield, 3.5–9.0 mS/cm improve tomato fruit quality (Dorai, Papadopoulos et al. 2001). Here, LC and PC averaged respectively at 1,9 and 1,6 mS/cm while P was down 0,3 mS/cm. Added to those measurements, the application of fertilizer solution (salinity of 1,4 mS/cm) could have raised those values. Thereby, putting the plant under salinity levels potentially affecting the yield and fruit quality. Thus, a comparison of the fruits nutritional quality depending on the GM used would be interesting as, generally, concentrations of minerals, carotene and vitamin C (among other compounds) increases in fresh fruit with increasing salinity (Dorai, Papadopoulos et al. 2001). Assessing of such parameters within the media comparison could implement furtherly their adoption, not only in regard of their performance, but also as beneficially contributing to public health.
The dry matter usually lower for compost than mineral soils, as peat mixtures are implemented with mineral material for improvement of the physical properties of the soils. The dry matter content of PC was found lower than that of LC and P, it was also found with and higher organic matter content. In principle a high soil organic matter in fine particles has the potential to hold water well. This could explain the lower water requirement of LC and PC compared to peat (Figure 8, A). The PC was quite coarse with big twigs and a very low density. Those parameters could have drained the soil but as the PC was only in SW, the roots had available water beyond their substrate. The low water provided to 'Golden Sunrise' in LC (Figure 8, B) is likely to be especially due to environmental conditions. That might include shading (as stipulated before) and an unfortunate leakage of the humidifier in the nursery room above that treatment.

An alkaline pH is usual in compost and is likely due to the consumption of organic acids by microbial activity during the composting process. Moreover, the higher NO3-N than NH4-N can potential increase pH along with the content in other charged nutrients and minerals. Peat bog are an acidic environement, the nutrient composition of peat does not stimulate microbial activity such as that the complex nutrient composition of compost does.

Subsequently, more hydrogen ions can be found in peat materials while in composts H+ are bound to molecules via the action of microorganisms. Regarding tomato physiological needs, the medium alkaline pH of PC and LC (respectively 7,4 and 7,6) can potentially interfere with the availability of P, K, Mn, B, Cu, Zn and Fe (Popescu and Dinu 2018). Signs of deficiency may be difficult to recognize, here, no major crop health issue linked to nutrient deficiency was found. (Schmilewski 2008) reported that the standard in composts are a pH of 8,6 and K2O of 1,650 mg/L and that those along with the high salinity content of compost are practically always incompatible with plants. The pH, salinity (EC) and potassium content of the composts were, indeed, higher than that of peat but remained in tolerable range for most plant growth and below the phytotoxic values reported above.

According to (Barrett, Alexander et al. 2016), two key element of the efficiency of a growing media in container-based production are its physical, chemical and biological properties necessary to support healthy root growth and its utilization practicality within the production system. The system in which the setup used in the experiments performed here have potential to be applied to are balcony garden. Humans and pigs have a comparable digestive system, hence the pig manure can be used for trials like these, when municipal brown waste was not available. The yield produced in that GM and its physicochemical properties assessed of its suitability to sustain tomato plants suggesting that a digestate from municipal waste streams could performed similarly. However, the acceptance of civilians concerning the use of composted fecal matter in balcony garden should be investigated. If the public does not embrace the use of human waste, despite its good performance, this could potentially limit the adoption of such compost in urban agriculture outside the industry. Besides, according to Norwegian regulations, sewage sludge for municipal wastewater streams is not approved for vegetable production, yet. It is a part of the SiEUGreen project to assess the problems related to human health when using human waste as growth medium. Researchers in Copenhagen University conducted comparisons of microflora and heavy metals in human waste and animal manure (Magid 2013). It was concluded that animal manure is far more prone though to be risky than human wastes, particularly with respect to the amount of pathogenic microorganisms, a potential source of human pathogens.

Vermicompost and composts based on plant waste material are safer for human health. However, following a viral infection in the greenhouses this medium was thought to be a potential source, investigation regarding this virus were performed as part of a special syllabus (Lacôte-Popovic 2020). The virus belonged to the family of *tobamoviruses*, those are causing great damages to tomato crops and several resistance breaking species outbreaks occurred within the last decades. As they are extremely stable and mechanically transmissible (Wilson 2014), infected composted food waste could potentially have contaminated the LC. Overall, the source of the outbreak was not identified, the seeds were thought to be a potential contaminant as well. Investigating further treatment option for the LC might be required to avoid those kinds of pathogens. Besides, for the application of this medium on balcony garden, the need to have a virus-free medium is of lesser importance than in commercial productions were this can have important economic cost and incidence on dense crops.

Finally, as discussed previously, reservoirs pots used in SW mitigated quality defects in the most susceptible variety. Its features also make the system very practical in urban agriculture, especially applied to balcony garden. Refilling was required about every three days for the most consuming plants and could be expended up to a week. This can be of great convenience for busy civilians or unexperimented gardeners. Moreover, on balconies, the squared shape of the pots and their wheels are interesting assets for space management.

Conclusion

The growing interest for urban agriculture, sustainability, self-sufficiency and recycling pushes the development and combination of technologies forward. Replacing the widely used peat mixtures with waste recycling show great promises. From biogas plant digestate and garden debris as well as kitchen waste and vermicompost of garden waste, growth media were made. Both PC and LC were found performant enough to sustain transplanted tomato plants growth and produce yield equivalent to that of a peat-mixture. Furtherly, the potential of brown water digestate as soil amendment in an urban area remains to be assessed in regards of health safety and public opinion. The variety 'Tastery' had interesting features, notably its resilience to cracking. The pots equipped with reservoir have great potential for balcony gardens, not only due to the flexibility of the watering but also as they seemed to prevent quality defect on 'Golden Sunrise' prone to skin cracks.

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