Development and experimental comparison of peat-free potting media for organic horticulture.

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Development and experimental comparison of peat-free potting media for organic horticulture.

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Abstract

The use of peat as a basis for growing substrates has allowed the horticultural sector to become increasingly efficient and industrialized, which nowadays makes peat an indispensable external input for a majority of horticultural businesses. As peat is considered a nonrenewable resource, whose extraction is recognized to have negative impacts on climate change, wetland ecosystems biodiversity and water regulating mechanisms, the organic regulations towards the use of peat are becoming stricter and the need to develop alternatives emerged. So far, alternatives have mainly been tested by substituting peat with one other material to different extends, but a single material which is able to substitute peat completely has not been found. This research is a study looking into the potential for peat substitutes using a mixture of materials. It was hypothesized that similar physical- and chemical characteristics to a commonly used peat based substrate have better effect on plant development and quality. Physical and chemical characteristics of nine different materials (wagram compost, vermicompost, wood fiber, coconut coir dust, lavasand, quarz sand, biochar, bark humus and horse manure substrate) are analyzed and according to the results four compositions created. In a pilot experiment, plant productivity of tomato and lettuce after six weeks of growth in the four compositions as well as on a commonly used peat based substrate "Bio Potgrond" and an already existing peat free substrate "Bio Erde" by Vermigrand is compared.

Diverse parameters such as plant height and biomass, flower production and nutrient uptake were measured and compared using one-way ANOVA and post-hoc tests.

Transplants grown on the peat substrate performed significantly better than those on the peat-free substrates. Plant productivity amongst peat free substrates was highest on substrates containing coconut coir instead of wood fiber, also significantly higher than on the peat free control "Bio Erde", indicating that the physical characteristics of coconut coir, which are similar to those of peat, have a major effect on plant growth. After the experiment plant nutrient contents were measured and nitrogen recovery calculated with results respective to the outcomes of the experiment, showing that next to the physical characteristics the nitrogen mobilization and availability of the substrates plays a major role.

In a follow-up experiment these results were taken into account, and an additional seven substrates were composed, which were on the one hand additionally fertilized with horn meal or vermicompost, and on the other hand contained different wood fiber brands, in order to find one, which is able to compete with coconut coir.

Due to small sample sizes in the follow up experiment, the results were not analyzed with statistical tests, and should therefor merely be used as an indication. The tomato transplants grown in the peat based Bio Potgrond were still performing the best, closely followed by a mixture with coconut coir and additional horn meal, as well as a mixture to which vermicompost was added. No wood fiber could be identified which led to better results than the one used in the pilot experiment. The results of the lettuce transplants in the follow-up experiment were to some extend controversial. The peat free Bio Erde performed better than the peat based Bio Potgrond, which is remarkable as in the pilot experiment this substrate performed significantly worse. External factors such as radiation and temperature may thus have a big effect on plant development and growth.

Although none of the substrates is proven to compete with the peat based substrate, this research provided a first approach for the development of peat-free substrates, and revealed the importance of more in depth research when using mixture substrates.

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1 INTRODUCTION

For about 60 years peat has been used as the main basis for potting media in commercial and private horticulture. Before that, potting media were mostly produced on farm from composted manure and other composted materials (Harrer, 2015). Due to its excellent structural and biophysical characteristics, the introduction of peat aided the industrialization of horticultural practices leading to a simultaneous mechanization and development of well adapted peat based substrates(Harrer, 2015) .
Advantages of using peat-based substrates depend on their favorable physical characteristics; they have a relatively low bulk density, a high porosity and a high nutrient exchange capacity, providing an optimal raw material in which the desired nutrient contents and pH can easily be adjusted. Peat-based substrates thus provide an ideal basis for plant propagation and growth (FiBL, 2005; Restrepo et al., 2013) and are nowadays widely used in horticultural practices. A study of 2010 revealed that per year 32 million m^3 of peat are used in European horticulture (Blievernicht et al., 2011). At the moment it is still very uncommon for the horticultural sector to use substrates that are not based on peat.

However, the sustainability of peat harvesting is widely criticized. Peat bogs are considered a habitat for several wetland species and are regarded as source of biodiversity. In addition they are an important sink of carbon and through their enormous water holding capacity are regarded as an important regulator for climate and water worldwide (Blievernicht et al., 2011). Peat bogs are influenced and threatened by the mining and the restauration of these ecosystems is almost impossible. WWF advocates for protection of the peat bogs, as they believe it takes decades to centuries for the peat to build up and their original state can never be reached again,(WWF, 2005).
However, companies use peat in their products tend to promote the use of peat as a sustainable practice, publishing numbers that represent the mined peat areas in relation to all peat resources available, not in relation to the ones that are already damaged (Klasmann, 2008). They rely on the idea that the peat is gathered from already agricultural used and destroyed wetlands only (Harrer, 2015), and that the amount of peat that is taken and used for horticulture is only a small percentage of the total existing and extracted peat.
Even if at the moment mostly already damaged peatlands are used for the extraction, peat resources are running out and even if not at the moment, in the future important wetland ecosystems will have to be destroyed in order to cope with the demand for peat. According to some(Harrer, 2015; Michel, 2010), peat is indispensable for horticulture nowadays showing that within 60 years, a sector became completely dependent on a non-renewable resource. At the moment the use of peat in organic agriculture is limited to horticultural practices by the EU regulation on organic farming and labels such as Bioland, Demeter or Naturland further restrict its use to 50 – 80% for growing media (Umweltinstitut, 2014). Taking into account that peat resources are declining and that organic regulations are becoming more extensive towards the use of peat, the market for peat-free alternatives is expected to grow and therefor there is need for further research into this topic (Freyer & Gollner, 2006).

1.1 ALTERNATIVES TO PEAT-BASED GROWING MEDIA

In order to develop suitable peat-free growing media, a range of physical, chemical, biological and economic criteria have to be considered (Schmilewski, 2008). These can be found in Table 1.

Table 1 - Properties of growing media and their constituents that pertain to "quality", adapted from (Schmilewski, 2008)

Physical	Chemical	Biological	Economic
Structure and structural stability Water capacity Air capacity Bulk density wettability	PH Nutrient content Organic matter Noxious substances Buffering capacity	Weeds, seeds and viable plant propagules Pathogens Pests Microbial activity Storage life	Availability Consistency of quality Cultivation technique Plant requirements price

Growing media are developed for several purposes. Substrates differ in their composition according to the type of plant, growing stage and cultivation technique they are developed for.
All-round substrates that are suitable for a broader range of plants and cultivation techniques also exist. Recent studies test alternative substrates based on different composts, distillery wastes, maize silage, coconut coir dust, wood fibers and cultured white *spaghnum* mosses (Bustamante et al., 2008; Emmel, 2013; Restrepo et al., 2013).
So far the studies indicate that peat substitution can be feasible (Emmel, 2013), but most studies focus on a reduction of the use of peat where peat is replaced with a single substitute product, for instance vermicompost or wood fiber, to different extends (N. Gruda & Schnitzler, 2004; Zaller, 2006). Studies that combine different substitutes are lacking. Moreover, the studies are often not focused on organic agricultural use, including mineral fertilization or fertigation into their experiments (Atiyeh et al., 2000).
Existing alternatives on the market are mostly used by hobby gardeners and not by commercial horticulture. According to experts (Grand, 2015), this is because the alternatives often don't allow for the increased standardized horticultural practices which are adapted to peat based substrates. The remaining cheap prices of peat further limit the use of alternatives (WWF, 2005).
The development of substrates from various materials or the comparison of different peat-free and organic substrates appears to be missing and furthermore it is not clear in how far the results of recent studies incorporate into practice. Therefor a practical and marketable approach is needed, focusing on available resources, development in cooperation with practitioners and comparison of different alternative peat-free substrates.
One alternative approach to peat-based substrates is the development of substrates based on composted materials, as it is done by the company Vermigrand, which is a farm and company located in Absdorf in lower Austria. The main product is vermicompost, made on farm from local organic materials. Furthermore, they have developed a peat free substrate, called "Bio Erde", which consists out of compost, bark humus, lava sand, vermicompost and coal. The substrate is mainly sold to Rewe business group, and they again sell it as organic subtrate for vegetable growing to the consumer, the organic label that is used is "Ja! Natürlich". In addition, Vermigrand produces a "Premium Bio-Erde", which is sold directly to consumers. The extent to which their products are used by commer-

cial horticulture is limited, which, according to Alfred Grand, is mainly caused by some physical and chemical restrictions of the substrate such as a relatively high salt content, high pH and very fine structure of the material.
In the coming two years the company is working together with a so called “operationelle Gruppe”, which is a group of farmers and practitioners with a common interest in a certain agricultural issue, which in this case is the reduction and substitution of peat in growing media.
Next to this Vermigrand wants to improve their current substrates towards a more professional one and also want to explore the use of new materials for their substrates such as coconut coir dust.
Experiments in which the performance of the “Bio Erde” is compared to peat based substrates that are commonly used in organic horticulture are lacking.

1.2 AVAILABLE COMPONENTS

In order to develop a peat-free substrate from several different materials, these have to be identified and their theoretic potential as a component in a peat substitute needs to be assessed. The following materials are available in the region and some of them already a compound of Vermigrands Bio Erde.

Wagram Compost:
The Wagram compost is a hot rotting compost made from materials that originate in the so called region “Wagram” in lower Austria. 40% Lucerne, 20% horse manure and 40% wood debris are the components which are used and treated on the farm owned composting plant. Before the introduction of peat as a growing medium, mainly composted materials were used as growing media. Studies reveal the benefits but also the constraints of different kinds of composts as peat substitution. The need to recycle an increasing amount of organic waste has led to an upsurge in the interest to use these materials for different purposes such as growing substrates (Restrepo et al., 2013). Several studies have been carried out in order to reveal the suitability of different kinds of composts for peat substitution (Bustamante et al., 2008; Zhang et al., 2013)
Not all kinds of composted material are equally suitable for peat substitution (Zhang et al., 2013). Some composts may have similar physical and chemical characteristics to peat and experiments with peat substitution have shown positive results with regard to plant biomass production and nutritional values (Bustamante et al., 2008). On the other hand several studies indicate that the high salinity of composts is the main limiting factor for seed germination and seedling growth (Bustamante et al., 2008; Garcia-Gomez et al., 2002; Sánchez-Monedero et al., 2004), which therefor represents the biggest constraint of compost used as peat substitution.

Vermicompost:
The vermicompost used in this study originates from the same materials that are used in the Wagram compost. After the Wagram compost is turned twice and underwent a short rotting phase, part of it is separated and used to produce the vermicompost. For this process a flow-through vermicomposting system is used in which a high density of compost worms (*E. Fetida* and *E. Andrei*), microorganisms, bacteria and fungi are found.
The suitability of vermicompost in general as a peat substitute for seedling growths has been tested in experimental setups before (Paul & Mezger, 2005; Zaller, 2006), the partly substitution of peat

based substrates with vermicomposted materials has shown significant positive results on plant growth, though the type of materials used to make the vermicompost is of major importance for its quality and its effect on plant development (Atiyeh et al., 2000). The positive effect of the vermicompost are ascribed to its high porosity, aeration, drainage, water holding capacity, microbial activity and its anti-phytopathogenic potential. In addition nutrients in vermicomposts are mostly found in plant available forms (Arancon et al., 2003).

Coconut coir dust:

The coir dust is a byproduct that remains when processing the thick husk of the coconut to all kind of products. What remains is coir pith tissue, short to medium length fibers and coir dust. Twenty years ago, coconut coir dust was already regarded a suitable substitution for peat in many ways; similar, or even higher structural stability, water holding capacity, drainage and cation exchange capacity were stated (Meerow, 1997). Other reports show that the chemical and physical characteristics of these materials have a high variability, depending on the origin and treatment (Abad, 2002). In addition, the particle size the material has when used as a potting medium, has a high influence on its water holding capacity and availability of nutrients (Noguera et al., 2003). According to this very different and sometimes opposed information regarding its suitability it becomes clear that the kind of coconut coir has to be chosen carefully and its characteristics should be known beforehand in order to develop a suitable peat substitution.

The coconut coir dust which was available for this study has been imported from India.

Wood fiber:

Wood fiber is the product of wood chippings that have been shredded under frictional pressure. Due to their physical and chemical characteristics wood fiber is classified a suitable peat substitute (N. Gruda & Schnitzler, 2006) by providing structure and aeration to a substrate. Furthermore, it has a neutral pH and a low salt content. The main limiting factor of wood fiber is its high C/N ratio resulting in a high rate of N-immobilization (N. Gruda et al., 2000). Furthermore, wood fiber has a higher drainage capacity in comparison to peat and depending on the particle size distribution, a lower water storage capacity, resulting in a higher irrigation frequency requirement, which can be unsuitable for common greenhouse practices.

Bark humus:

Bark humus is the result of composted bark, which is a residual from coniferous trees used in wood production. It is widely used as an additive in peat reduced growing media (Reinhofer et al., 2006) and considered a suitable material for peat substitution, as it has a favorable pH, low salt content, high aeration- and water holding capacity, as well as a favorable nutrient composition (FiBL, 2005).

Biochar:

The biochar used in this study originates from Austria, where it is made from wood which originates from a PECF certified sustainable forest. The wood and wood debris is carbonized. Biochar is considered free from pathogens, has a low nutrient content and has a very high structural stability (Steiner & Harttung, 2014). Studies about the use of biochar as a soil amendment indicate that there is a positive effect of biochar in soils on microbial activity as well as on the water retention capacity

(Mulcahy & Dietz, 2013; Warnock et al., 2007). These can be considered the biggest advantages when used as a peat substitution.

2 AIM OF THE STUDY

The aim of this study is to develop peat-free growing substrates for organic vegetable transplant production from available components and to evaluate the suitability of these substrates.
The substrate should have its application in the timespan between pricking out the seedlings until they can be sold or transplanted as young vegetable plants. The suitability will be evaluated based on the chemical and physical characteristics of the substrates and in addition an experimental comparison will be conducted to evaluate the effect on plant development and quality.
Based on the results recommendations can be made regarding the further development of the substrates and the need for further research into this topic.

2.1 RESEARCH QUESTIONS

The following research question derive from the purpose of the study:

GRQ: What are the characteristics of the available components and what is the performance of the developed peat-free substrates for the production of organic vegetable transplants?

SRQ1: What are the physical and chemical characteristics of the available materials?

SRQ2: What are the physical and chemical characteristics of the developed substrates before and after the experiment?

SRQ3: What is the effect of the different substrates on plant development and quality?

2.2 HYPOTHESIS

The development and evaluation of peat-free substrates is mostly done based on knowledge about materials and substrates gained in recent studies.
Often peat is considered the optimal material and comparisons are done with a reference to peat such as indicated in table 2:

Table 2 - Suitability of commonly used peat substitutes, adapted from (FiBL, 2005)

	Physical and Chemical Characteristics							Sustainability	
	pH	Nutrients	Salt	N-fixation	Water holding capacity	Air-filled pore ratio	Structural Stability	Origin	Renewable resource
Peat	Low	●○○	●●●	●●●	●●●	●●○	●●○	Europe	No/to a certain extend
Green compost	High	●●●	○○○	●○○	●○○	●○○	○○○	Local	yes
Wood fiber	Low - Neutral	○○○	●○○	●○○	●○○	●●○	●○○	Regional	yes
Coconut coir	Low - Neutral	●○○	●●	●●○	●●○	●●○	●●○	Overseas	yes

○○○ **Low/Not ideal** ●●● **High/Ideal**

According to some (Freyer & Gollner, 2006) a peat-free substrate should generally have the same characteristics as peat based substrates. From this statement, the hypothesis can be derived:

The more a substrate resembles the physical and chemical characteristics of a commonly used peat based substrate, the better is its effect on plant development and quality.

3 METHODS AND MATERIALS

The conducted study is an explorative study consisting out of a pilot experiment and a follow-up experiment, in which results of the pilot experiment were used to improve the substrates further.

3.1 THE PILOT EXPERIMENT

3.1.1 Test Materials

From the available materials, four new substrates were developed, that represent the experimental treatments. Materials that were available for the development of these substrates are:

- Wagram Compost
- Vermicompost
- Wood fiber
- Coconut coir dust
- Lavasand
- Quarzsand
- Biochar (coal)
- Bark humus
- Horse manure substrate

The developed substrates were compared to a control substrate. Frequently applied in organic horticulture and also used in experimental comparison before is the peat-based substrate "Bio-Potgrond", from Klasman-Deilmann GmbH.
In addition, the substrates were also compared to the peat free substrate from Vermigrand "Bio-Erde".

3.1.1.1 Substrate development and evaluation

For the development of the substrates, the available materials and the control substrates were analyzed in more detail.
In laboratory analyses the following parameters were measured:

- Nitrogen (total N and available NO_3 and NH_4 in mg/g)
- Potassium (K in mg/g)
- Phosphorus (P in mg/g)
- Organic Carbon (g/kg)
- pH ($CaCl_2$)
- Electrical Conductivity (EC value in mS/cm)
- Dry bulk density (kg/L)
- Water holding capacity (mL/L)

The quality of the substrates is determined by its physical and chemical characteristics, which directly depends on the individual materials used and which can be estimated based on the composition.
The same parameters were measured from the readily mixed substrates, in order to verify the estimations.

The nutrient contents of horticultural substrates are commonly expressed in mg per liter of substrate, which is why in this report the contents are also expressed in this unit.

3.1.2 Experimental Setup and Exposure Conditions

For answering the third sub research question an experiment was conducted.
Testing took place with two cultures: Tomato (*S. Lypocersicum var Cerasiforme)* and Lettuce (*L. Sativa var Capitata*). Tomato represents a plant commonly grown in substrates and sold as young vegetable plants to consumers and farmers for further propagation, furthermore it is a high nutrient demanding plant. In comparison to this, lettuce is a low nutrient demanding plant and can develop to a high extend within the scope of the experiment.
First, the seedlings were established from organic seeds all in the same peat free propagation substrate, provided by Vermigrand.
The propagation took place in commonly used propagation trays until the time of pricking out and transplanting them into the different developed substrates/the experimental variants, after approximately 16 days, depending on the development of the tomato plants, which should be pricked out at two-leaf stage (N. Gruda & Schnitzler, 2004).
Seedlings were transplanted into pots with a diameter of 10.5cm and a volume of 0.5l. 8 pots were placed on trays of 0.6mx0.35m, leaving enough interspace to minimize disease pressure.
Per variant and culture 5 trays were set up, representing 5 replications of the experimental setup:

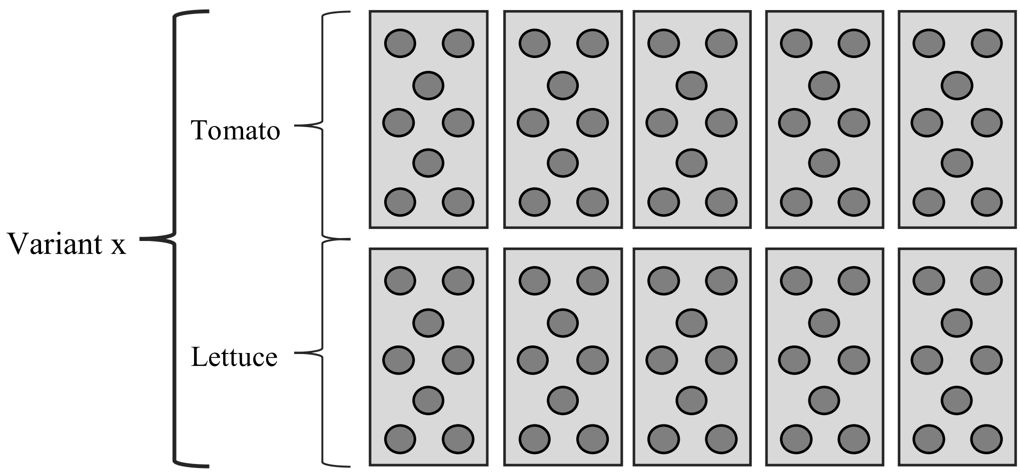

Figure 1 - Experimental Setup of the pilot experiment

With this setup and 6 substrates a total of 480 plants, 56 liters of substrate per variant and 16 m^2 of greenhouse surface area are needed.
The circumstances in the greenhouse were kept as identical as possible for all plants. This means temperature, humidity and irrigation were the same for all plants, in addition regular rotation of the setup was conducted to make sure that possible systematic differences did not influence the results.

Irrigation took place according to a set schedule. For this setup, a drip irrigation was used in combination with an automatic irrigation computer which depending on the stage of the plants and the environmental circumstances applied 150 to 500 ml per plant per day.

To measure the effect of the substrates on plant development and quality comparable experiments were used as a reference for conceptualizing these terms. The shoot length and biomass can be considered important indicators for the effect of the substrate on the plant development (Freyer & Gollner, 2006; Zaller, 2006). The quality of vegetable transplants can furthermore be measured by the amount of leafs and flowers (Paul & Mezger, 2005).
The following parameters were measured after 6 weeks of growth in the different variants:

- Plant height: measured from substrate surface to vegetation point in cm
- Amount of leafs
- Fresh biomass in g/plant
- Dry biomass in g/plant
- Flower production (for tomatoes only) in amount/plant
- Nutrient uptake (N, P, K, Mg) measured in the dry plant biomass in mg/g
- Apparent N-recovery as the percentage of nitrogen taken up by the plant of the total nitrogen provided in the beginning of the experiment

3.2 Follow-up Experiment

In order to gain more insight on the performance of peat-free substrates made from different materials, seven additional substrates were developed for the follow-up experiment, based on the results of the pilot experiment.

3.2.1 Materials

In addition to the Materials used in the pilot experiment, the following materials were used:

- Horn meal
- Different brands of Wood fiber: Firestixx, Austaller, Kleeschulte, Ziegler

The seven new substrates were compared to the same peat based control substrate “Bio-Potgrond” and to the peat free “Bio-Erde”.
In contrast to the pilot experiment, the different wood fiber brands and developed substrates in this experiment were not examined for their physical and chemical properties prior to the experiment due to time restrictions.

3.2.2 Experimental setup

The Set-up of the second experiment is resembled by Figure 2. Seedlings were established and transplanted the same way as in the first experiment.
Four pots were placed on one tray and per variant and culture 4 trays were set up, representing 4 replications of the experimental setup. A total of 288 plants were grown in this experiment.

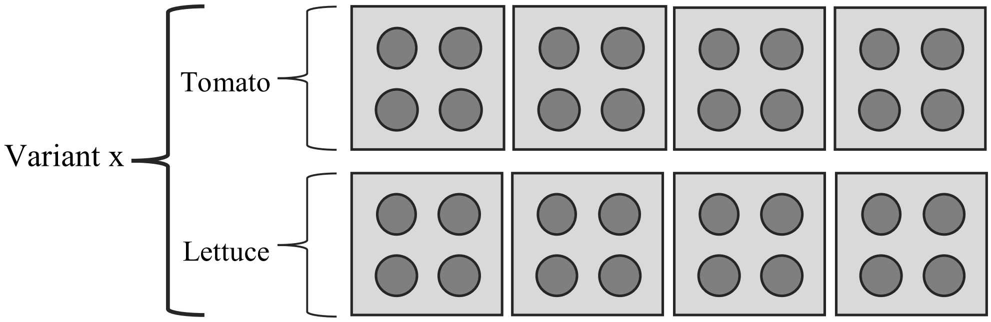

Figure 2 - Experimental Setup of the follow-up experiment

The following parameters were measured after 6 weeks of growth in the different variants:

- Plant height: measured from substrate surface to vegetation point in cm (for tomatoes only)
- Fresh biomass in g/plant
- Flower production (for tomatoes only) in amount/plant

3.3 STATISTICAL INTERPRETATION

The statistical analyses of the pilot experiment were based on the one-way analysis of variance (ANOVA), in which for the two different vegetable species the mean values for each parameter and each treatment (substrate) were analyzed in order to reveal statistically significant differences. ANOVA was chosen as the most suitable test after the data was checked for normality and homogeneity of variances using the Shapiro –Wilk and Levene´s test respectively. As these tests revealed violations of these assumptions, a transformation of the data was conducted. According to literature (Howell, 2012; Tabachnick & Fidell, 2007) a logarithmic transformation is suitable if the data reveals substantially positive skewness, which was the case. In addition, it is recommended to add a constant to the values, so that the minimum score is 1. After the transformation, the data showed a normal curve of distribution, and for most measured parameters the variances of the different groups could be called equal. As ANOVA is a robust testing method with regard to the violation of these assumptions in the case of equal sample sizes, the remaining deviations were ignored and the ANOVA was executed. In order to reveal the differences between the different treatments, post-hoc tests were done. For the case of lettuce, for which homogeneity of variances was assumed according to the Levene´s test, Tukey HSD test was used, for tomato this was not fully the case, even after the transformation. Here the Games-Howell test was done, in which equal variances are not assumed.

As the data of the follow-up experiment did not meet the assumptions regarding normality and homogeneity of variances, even after a transformation, one-way ANOVA was not suitable. A non parametric test, such as the Kruskal-Wallis test was not performed either, as the distribution of the groups did not have the same shape or variability, making an interpretation of the results of a Kruskal-Wallis test unreliable (McDonald, 2014).

All tests were conducted with Version 23 of IBM SPSS Statistics.

3.4 SUBSTRATE DEVELOPMENT AND EVALUATION

3.4.1 Physical and chemical characteristics of the materials

Nine different materials have been analyzed, showing a high variability. Physical and chemical characteristics, as well as nutrient contents are presented in Tables 3 and 4.

Table 3 – Physiochemical characteristics of the available materials

Sample	Name	pH (CaCl2)	EC (uS/cm)	% OM	C:N Ratio	Bulk Density (kg/l)	Max WHC (%)
1	Coconut coir	6.0	169	64	78	0.13	548
2	Wood fibre	4.8	68	99	467	0.04	649
3	Quarzsand	7.4	20	0	0	1.68	6
4	Bark humus	7.5	470	32	23	0.38	142
5	Wagram compost	8.7	2772	33	10	0.44	127
6	Vermicompost	8.0	3674	21	9	0.66	67
7	Biochar	8.1	254	56	50	0.33	144
8	Horse manure substrate	7.9	5071	71	24	0.14	240
9	Lavasand	7.4	53	2	0	0.86	45

Table 4 – Total and available Nutrient contents of the available materials

Sample	Total			Available			
	% N-tot.	% P-tot.	% K-tot.	mg N-NH4 per Kg	mg N-NO3 per kg	mg P-PO4 per kg	mg K per kg
1	0.4	0.0	1.3	2.6	0.1	1.1	52
2	0.1	0.0	0.2	2.0	0.0	0.6	25
3	0.0	0.0	-	1.7	0.0	0.1	38
4	0.8	0.1	0.5	12.0	0.1	4.6	608
5	1.5	0.4	2.0	21.7	87	17.4	6065
6	1.2	0.4	2.0	13.1	467	37.8	8218
7	0.6	0.0	0.4	2.4	0.1	0.1	436
8	1.3	0.4	2.5	13.1	0.2	25.4	-
9	0.1	0.3	-	6.5	0.1	7.5	149

3.4.2 Substrate composition

The substrates were composed having different levels of similarity to the control peat substrates regarding nutrient content as well as physiochemical characteristics. At the same time the composed variants are a modification of the Bio Erde, as this substrate was meant to be improved. The main restrictions of the existing Bio Erde were identified as the relatively high pH, the high salt content which is caused by a high Potassium content of the composts and the fine structure of the substrate.

The reasons for not making use of the horse manure substrates are its extraordinary high electrical conductivity, which is an indicator for a high salt content. Lavasand in comparison to quarzsand revealed a more favorable water holding capacity as well as bulk density and was thus preferred.

Table 5 shows the results of the final substrate composition.

Table 5 – The developed treatments and their components in volume %

Treatment	Wagram compost (Vol %)	Vermi compost (Vol %)	Coconut coir (Vol %)	Wood fiber (Vol %)	Bark humus (Vol %)	Biochar (Vol %)	Lavasand (Vol %)
Bio Erde	25	3	0	7,5	60	3	7,5
Mix 1	18	3	0	30	47	3	5
Mix 2	18	3	30	0	47	3	5
Mix 3	18	5	0	53	30	0	0
Mix 4	18	5	53	0	30	0	0

In order to develop a substrate which has lower pH, a lower salt content and an increased structure, an increased amount of wood fiber or coconut coir was added to the Bio Erde. In both Materials a high potential as a peat substitute had been identified, and the measured high water holding capacity, low bulk density and relatively low pH, support these findings. Variants 1 and 3 are direct modifications of the Bio Erde, in which the amount of wood fiber or coconut coir was increased to 30 Vol % respectively.
Variants 3 and 4 have even higher percentages of wood fiber and coconut coir respectively, biochar and lavasand were not added to those variants, in order to simplify the composition.
Prior to the laboratory analyses, the nutrient contents of the compositions were estimated based on the measured nutrient contents of the individual materials. The values estimated for the peat based Bio Potgrond are based on information provided by the production company, as presented in Table 6.

Table 6 – Estimated Nutrient contents of the developed substrates

Treatment	Total			Available		
	N (mg/l)	P (mg/l)	K (mg/l)	N-NH4 + N-NO3 (mg/l)	P-PO4 (mg/l)	K (mg/l)
Bio Potgrond	400-500	250-450	350-700	80-120	250-450	350-700
Bio Erde	3742	908	3847	49	9	2154
Mix 1	2895	685	2982	41	8	1652
Mix 2	3034	697	3458	41	8	1660
Mix 3	2481	559	2862	48	7	1698
Mix 4	2727	580	3703	49	7	1713

The estimations of the peat free substrates reveal much lower available Nitrogen and Phosphorus contents than the control substrate, though the variants and the Bio Erde don't reveal major differences amongst each other. The estimated potassium content was decreased in the variants, which was one of the objectives and which was the reason not to try to reach the same level of available N as in the control variant by adding organic manure or vermicompost, as this would also have increased the potassium content and possible the pH. After making the estimations and agreeing on the compositions, the mixtures were undertaken laboratory analyses.

The biochemical and physical characteristics of the developed substrates, as presented in Table 7, reveal most modifications from the Bio Erde in their bulk density and water holding capacity. The pH was only lower in the variants with coconut coir.

Table 7 – Biochemical and physical characteristics of the substrates before the experiment

Treatment	pH	EC (mS/cm)	C/N	Bulk Density (kg/l)	Max. Water Holding Capacity (%)
Bio Potgrond	5.1	2.36	28	0.19	330
Bio Erde	8.0	2.50	13	0.49	127
Mix 1	8.1	2.30	15	0.43	136
Mix 2	7.7	2.24	16	0.4	159
Mix 3	8.1	3.12	14	0.35	163
Mix 4	7.5	2.71	16	0.32	208

The measured available nitrogen contents were even lower than estimated for the peat free mixtures and even higher for the Bio Potgrond. In Table 8, all results of the laboratory analyses regarding nutrient contents are presented.

Table 8 - Measured available and total nutrient contents before the experiment

Treatment	N-NH4 + N-NO3 (mg/l)	P-PO4 (mg/l)	K (mg/l)	N (mg/l)	P (mg/l)
Bio Potgrond	157	49	448	2410	193
Bio Erde	40	6	2430	4912	1194
Mix 1	22	6	2097	4126	1045
Mix 2	26	8	1852	3699	901
Mix 3	24	7	2282	4096	905
Mix 4	44	11	1799	3437	750

4 RESULTS AND INTERPRETATION

4.1 EXPERIMENTAL OUTCOMES

4.1.1 The effect on plant development and quality

The results of the pilot experiment for Lettuce and Tomato can be seen in Tables 9 and 10.

Table 9 - Mean values, standard error and significance of measured parameters for the crop Lettuce

Lettuce			
Treatment	Weight (g)	Leaf (#)	Dry weight (g)
Mix 1	15.7 ± 0.5^{b}	21.7 ± 0.5^{b}	1.7 ± 0.1^{b}
Mix 2	32.6 ± 1.2^{d}	28.1 ± 0.5^{e}	3.3 ± 0.3^{d}
Mix 3	12.3 ± 0.7^{a}	19.9 ± 0.5^{a}	1.2 ± 0.1^{a}
Mix 4	36.8 ± 1.4^{d}	29.0 ± 0.6^{c}	2.8 ± 0.1^{cd}
Bio Erde	26.5 ± 0.7^{c}	29.0 ± 0.4^{c}	2.5 ± 0.1^{c}
Bio Potgrond	74.4 ± 1.9^{e}	38.6 ± 0.6^{d}	4.9 ± 0.2^{e}

The sample size per variant is n = 40. Mean values in columns followed by the same letter are not statistically significant according to the Tukey HSD test with a significance level of P < 0.05.

Table 10 - Mean values, standard error and significance of measured parameters for the crop Tomato

Tomato					
Treatment	Weight (g)	Leaf (#)	Dry weight (g)	Height (cm)	Flower (#)
Mix 1	17.1 ± 1.0^{b}	9.3 ± 0.2^{a}	2.4 ± 0.1^{b}	33.6 ± 0.8^{b}	2.8 ± 0.4^{b}
Mix 2	23.9 ± 0.6^{dc}	10.2 ± 0.2^{b}	3.4 ± 0.1^{dc}	39.9 ± 0.5^{dc}	5.2 ± 0.3^{c}
Mix 3	11.1 ± 0.9^{a}	9.3 ± 0.3^{a}	1.6 ± 0.1^{a}	23.0 ± 0.6^{a}	1.1 ± 0.3^{a}
Mix 4	26.9 ± 1.0^{d}	10.5 ± 0.3^{b}	3.8 ± 0.1^{d}	41.4 ± 0.6^{d}	6.0 ± 0.2^{c}
Bio Erde	21.5 ± 0.7^{c}	10.1 ± 0.2^{b}	3.1 ± 0.1^{c}	37.5 ± 0.6^{c}	5.3 ± 0.3^{c}
Bio Potgrond	58.7 ± 1.6^{e}	14.3 ± 0.4^{c}	9.6 ± 0.2^{e}	73.1 ± 1.4^{e}	13.3 ± 0.6^{d}

The sample size per variant is n = 40. Mean values in columns followed by the same letter are not statistically significant according to the Games-Howell test with a significance level of P < 0.05.

The pilot experiment revealed significant differences in the performance of the different substrates. The transplants grown in the peat based Bio Potgrond performed significantly better in all measured parameters. Already the analyses of the mixtures revealed the difficulty of composing substrates with similar physical as well as nutritional characteristics to peat based substrates. As long recognized, nitrogen availability has a major effect on transplant development and growth (FiBL, 2005), the result of this experiment can on the one hand be ascribed to the high Nitrogen availability and nutrient balance in general of the Bio Potgrond in comparison to the peat free substrates as seen in Table 8. In addition, the success of the peat based substrate is also a result of its low pH, high water holding capacity and low bulk density as all factors were identified before the experiments as crucial factors of success and the developed substrates did not meet these requirements to the full extend. This finding is further supported by the fact that Mix 4 performed in most cases, especially in weight and height parameters, significantly better than the other developed substrates including the Bio Erde. The difference of available Nitrogen between Mix 4 and the Bio Erde in the beginning of the experiment is negligible, thus other factors must have led to this significant difference in plant growth. Mix 4 is the only variant in which coconut coir was used instead of wood fiber, a material previously identified with a high potential for peat substitution. The analyses of the mixtures revealed indeed, that Mix 4 had the most similarities to the Bio Potgrond. The potassium content was much lower in comparison to the Bio Erde, the bulk density was decreased, which might have led to a higher aeration of the substrate and the water holding capacity of Mix 4 was also the highest amongst the peat free treatments. As external factors such as temperature, radiation and irrigation were the same for all treatments, it is likely that these described factors led to the higher performance of Mix 4.

The nutrient contents of the substrates were measured at the beginning of the experiment, thus the behavior of the nutrient availability over time can only be estimated, for this the N mineralization in the substrates during the experiment should be taken into account and is another determinant of the performance.

Even though the C/N Ratio of the peat free substrates didn’t reveal much difference as seen in Table 7, it is probable that there is a difference due to the different characteristics of the single materials such as the C/N Ratio of wood fiber and coconut coir and the different amounts of these materials used in the mixtures.

4.1.1.1 Nutrient contents

The nutritional status of the transplants was only significantly different between the Bio Potgrond and the peat free substrates for N, P and Mg. There was no significant difference between the composed mixtures and the Bio Erde. The Tomato transplants grown in the Bio Potgrond showed in all cases a significant lower nutritional value for N, P and Mg. The nutrient contents of the lettuce were only significant for P and Mg. Here the peat substrate led to significantly higher contents I the transplants than in most of the other substrates.

The results are presented in Tables 11 and 12.

Table 11 - Mean values, standard error and significance of nutrient contents - Tomato

Tomato				
Treatment	% N-tot.	% P-tot.	% K-tot.	% Mg-tot.
Mix 1	1.36 ± 0.09[b]	0.22 ± 0.01[b]	3.43 ± 0.27	0.89 ± 0.00[ab]
Mix 2	1.22 ± 0.04[b]	0.22 ± 0.01[b]	3.44 ± 0.10	0.87 ± 0.01[b]
Mix 3	1.45 ± 0.09[b]	0.22 ± 0.01[b]	3.19 ± 0.06	0.95 ± 0.04[b]
Mix 4	1.21 ± 0.08[b]	0.24 ± 0.01[b]	3.28 ± 0.12	0.96 ± 0.04[b]
Bio Erde	1.22 ± 0.04[b]	0.22 ± 0.01[b]	3.08 ± 0.03	0.84 ± 0.01[b]
Bio Potgrond	0.93 ± 0.03[a]	0.14 ± 0.01[a]	2.89 ± 0.09	0.72 ± 0.04[a]
P	0.000	0.000	0.061	0.000

The sample size per variant is n = 5. Mean values in columns followed by the same letter are not statistically significant according to the Tukey HSD test with a significance level of P < 0.05

Table 12 - Mean values, standard error and significance of nutrient contents – Lettuce

Lettuce				
Treatment	% N-tot.	% P-tot.	% K-tot.	% Mg-tot.
Mix 1	1.79 ± 0.06	0.23 ± 0.01[a]	5.99 ± 0.22	0.47 ± 0.02[a]
Mix 2	1.80 ± 0.05	0.28 ± 0.01[a]	6.30 ± 0.15	0.49 ± 0.01[a]
Mix 3	2.00 ± 0.10	0.24 ± 0.01[a]	6.24 ± 0.31	0.50 ± 0.01[a]
Mix 4	1.91 ± 0.08	0.34 ± 0.01[b]	6.16 ± 0.15	0.55 ± 0.01[b]
Bio Erde	1.74 ± 0.06	0.27 ± 0.01[a]	5.83 ± 0.17	0.47 ± 0.01[a]
Bio Potgrond	1.96 ± 0.06	0.33 ± 0.01[b]	5.90 ± 0.18	0.69 ± 0.02[c]
P	0.065	0.000	0.518	0.000

The sample size per variant is n = 5. Mean values in columns followed by the same letter are not statistically significant according to the Tukey HSD test with a significance level of P < 0.05

The reason for the contrary results between the lettuce and tomato plants can be found in the measuring procedure. The nutrient contents have been measured in the whole aboveground plant, which in case of tomato transplants includes stems and leaves. In case of lettuce the whole aboveground plant exists of only leaves.

In the case of tomato, the significant lower nutrient contents of the transplants grown in the control peat substrate can thus be ascribed to the fact that the control substrate led to plants that are relatively high and thus have a larger stem leaf ratio. The stem contains less nutrients than the leaves, and thus the contents are lower for the whole plant.

In addition to the total plant nutrient contents, also the average nitrogen recovery per treatment was calculated as the percentage taken up by the transplants of the total and available nitrogen provided in the beginning of the experiment. The result can be seen in table 13:

Table 13 - Nitrogen recovery of Tomato and Lettuce

	N recovery % total	
Treatment	Tomato	Lettuce
Mix 1	1.6 ± 0.1	1.5 ± 0.0
Mix 2	2.2 ± 0.1	2.9 ± 0.2
Mix 3	1.1 ± 0.1	1.1 ± 0.1
Mix 4	2.7 ± 0.2	3.1 ± 0.2
Bio Erde	1.4 ± 0.1	1.8 ± 0.1
Bio Potgrond	7.4 ± 0.2	8.0 ± 0.2

The nitrogen recovery is remarkably higher in the peat based substrate than in all the peat free substrates. Amongst the peat free substrates, the two mixtures with coconut coir are showing the highest results, which relates to the significant higher biomass of these transplants.
The nitrogen recovery can also be expressed in mg of nitrogen taken up per liter of substrate as seen in Table 14:

Table 14 - Total N uptake in mg per litre of substrate

	N uptake (mg/l)	
Treatment	Tomato	Lettuce
Mix 1	66	62
Mix 2	81	107
Mix 3	45	45
Mix 4	93	107
Bio Erde	69	88
Bio Potgrond	178	193

Using this way of expressing the nitrogen recovery gives an indication for the actual amount of nitrogen mineralization which at least must have taken place in the substrates during the experiment, as all values exceed the initial amount of available nitrogen. The results clearly show, that next to the physical characteristics of coconut coir, which were the most similar to peat, also the nitrogen availability of the peat free mixtures with coconut coir are probable to have led to the positive results regarding plant growth.

4.2 THE FOLLOW-UP EXPERIMENTS

As all developed substrates were significantly worse in their performance than the peat substrate, a second set of experiments with further developed substrates was conducted, in which identified deficits were taken into account.

One of the main deficits identified in the developed substrates was their lack of plant available nitrogen. By adding a large amount of wood fiber or coconut coir dust to the substrates in the pilot experiment in order to improve the structure, decrease the pH and the potassium content, also a higher C/N ratio and lower available nutrient contents were the result, which probably affected the performance in a negative way. The follow-up experiment was thus designed to build upon these first insights.

Commonly used and recommended as an organic fertilizer in peat reduced and peat free substrates is horn meal (FiBL, 2001).

Typically horn meal has 14 % Nitrogen with a fast rate of mineralization (Bioland/KÖN/FiBL, 2005) and thus adding 2 kg horn meal/m^3 substrate will lead to a Nitrogen fertilization of 280 mg/l.

In the previous experiments mixture 4, with an increased amount of coconut coir dust, showed a significantly better performance in comparison to the other peat free substrates. This was not only referred back to the nutritional attributes of the material, but also to its favorable physical characteristics which are similar to peat. Based on the fact, that coconut coir dust has to be imported from overseas, the company Vermigrand is not in favor of making use of this material in the long term and alternative materials need to be used.

This is why in the follow-up experiment different wood fiber brands were compared in order to test if they differ amongst each other.

The compositions of the treatments used in the follow-up experiment are presented in the table below:

Table 15 - Composition of variants in follow-up experiment

Treatments	Wagram Compost (Vol %)	Vermi-compost (Vol %)	Coconutcoir (Vol %)	Woodfiber (Vol %)	Barkhumus (Vol %)	Biochar (Vol %)	Lavasand (Vol %)	Type of fiber and brand	Horn (kg/m^3)
Bio Erde	25	3	0	7.5	60	3	7.5	Wood: Firestixx	0
Mix 1	25	3	0	7.5	60	3	7.5	Wood: Firestixx	2
Mix 2	25	6	0	7.5	60	0	7.5	Wood: Firestixx	0
Mix 3	18	3	0	25	55	0	5	Wood: Firestixx	2
Mix 4	18	3	0	25	55	0	5	Wood: Austaller	2
Mix 5	18	3	0	25	55	0	5	Wood: Kleeschulte	2
Mix 6	18	3	25	0	55	0	5	Coconut coir	2
Mix 7	18	3	0	25	55	0	5	Wood: Ziegler	2

The results of the follow-up experiment are presented in Table 16 and 17.

Table 16 - Results of follow-up experiments - Tomato

	Tomato		
Treatment	Fresh Weight (g)	Height (cm)	Flower (#)
Bio Potgrond	56 ± 5	38 ± 1	5.6 ± 0.7
Bio Erde	31 ± 3	27 ± 1	1.3 ± 0.2
Mix 1	40 ± 3	31 ± 1	4.0 ± 0.5
Mix 2	50 ± 6	33 ± 1	5.1 ± 0.6
Mix 3	31 ± 3	27 ± 1	3.4 ± 0.6
Mix 4	42 ± 10	30 ± 2	5.1 ± 0.7
Mix 5	42 ± 7	31 ± 1	4.3 ± 0.9
Mix 6	50 ± 7	33 ± 1	5.5 ± 0.5
Mix 7	26 ± 4	26 ± 1	1.1 ± 0.4

The sample size per treatment is n = 16.

In the case of the tomato transplants, the peat based Bio Potgrond led to the best results. Though, the difference of the mean between the Bio Potgrond and the developed variants was smaller than in in the pilot experiment. The tomato transplants grew best in variants 2 and 6, which were the mixtures with an increased amount of vermicompost instead of horn and coconut coir dust instead of wood fiber respectively. These results show, that coconut coir still must be more favorable in terms of physical characteristics in comparison to the different brands of wood fiber, as differences in nutritional status are assumed to be equaled out by the fertilization with horn meal.
Also remarkable is the positive result of the increased addition of vermicompost in variant 2. The performance is as good as the one of the coconut coir based substrate and the difference to the peat based Bio Potgrond is much smaller than in the pilot-experiment.

Table 17 - Results of follow-up experiments - Lettuce

Lettuce	
Treatment	Fresh Weight (g)
Bio Potgrond	57 ± 7
Bio Erde	61 ± 4
Mix 1	76 ± 4
Mix 2	37 ± 3
Mix 3	57 ± 4
Mix 4	35 ± 2
Mix 5	50 ± 3
Mix 6	57 ± 3
Mix 7	48 ± 4

The sample size per treatment is n = 16.

Lettuce d the best results in Mix 1 and in the Bio Erde, in both variants a better performance than in the peat based Bio Potgrond was achieved. This is especially remarkable in comparison to the results of the pilot experiment. The Bio Erde performed much better in the follow-up experiment than before, which must be due to differences in temperature, as all other external factors could be controlled and were kept the same in both experiments. Furthermore, lettuce is a lower nutrient demanding plant than tomatoes, and thus a substrate with a lower nutrient availability might be favorable, even though this does not explain the difference of the same substrates in the two experiments. As the data of the follow-up experiment was not suitable for statistical interpretation these results should merely be used as an indication and basis for following research.

5 DISCUSSION AND RECOMMENDATIONS

The development of peat free substrates and their experimental comparison revealed the potential but also the complexity of substrates composed out of several different materials in order to substitute peat. Even though the search for peat-free potting media in organic horticulture has been going on for a long time, and the pressure on substituting peat is increasing due to stricter regulations, horticultural farms still depend on peat-based substrates for their production and only a partly reduction of peat in the substrates has been achieved so far.
Experimental comparisons indicate that a complete peat-free substrate using a single other material is not feasible, as the assessed materials are simply not competitive to peat.
Also in this study the results of the peat based substrate was by far the best. This success is traced back mainly to the well-balanced nutrient contents, the favorable physical characteristics and the lack of available nitrogen in the peat free treatments. Comparing the newly developed substrates revealed that besides nutrient contents, physical characteristics are as important and highly affect plant development and quality. Therefore, future studies aiming to find competitive peat-free substrates should focus on improving these qualities. In order to compete with peat, peat-free substrates should be composed out of several different materials, where each of them fulfills a specific role and adds different values to the substrate. This makes the process complex, as each material can also have drawbacks or disadvantages for a substrate which need to be taken into account. Furthermore, the substrates quality can change when only one of the components is missing or changing in quality.

This study employed materials that were locally available or easily accessible, and this variability of available materials in different regions of the world reveals another complex issue in the development of peat-free substrates. If, like in this case, the requirement is also to only use local materials for the peat substitution, the development of peat free substrates becomes more complex. In this case the substrates with a high amount of coconut coir dust outperformed all other peat free substrates, and it seems not to be simple to find a similar local material, like it was tried in the follow-up experiment. Trade offs seem necessary in order to create scientific evidence showing feasibility of peat substitution by a mixture of components.
Comparing the results of the pilot- and the follow-up experiments show performance depended on specific external factors. In both experiments the setup was the same and all factors that could be regulated, such as irrigation, shading and spacing were similar. However, the pilot-experiment mainly took place in May and June, whereas the follow-up experiment was conducted between the mid July and mid September. Temperature was not regulated in the greenhouse and likely caused the observed different performances of the control substrates.

For a comprehensive assessment of the eligibility of peat free substrates in organic horticulture, not only chemical and physical analyses or an experimental evaluation of their effect on plant development and quality are required, but one must also take into account the technical feasibility of a substrate, an economic evaluation as well as the environmental impact of the substrates.
Especially in an increasingly mechanized agriculture, technical feasibility, such as the suitability of a substrate for press pot machines and hydraulic properties of substrates, such as the wettability determining irrigation feasibility and water saving potential are important (Schindler et al., 2016), and

determine whether also modernized horticultural farms will be able to make use of peat free substrates.
An economic as well as an environmental evaluation of the developed substrates in this study is missing. The physical and chemical characteristics and the effect of a substrate on plant development and quality are main quality indicators and form the underlying basis for a successful substrate. Unlike the other substrates, peat has a stable- and low price, which is one of the main factors for its success. This is only possible at the expense of environmental impacts as a recent study has revealed: In comparison to a wide variety of alternative materials, of which many have also been used in this study, peat is by far the worst alternative regarding global warming potential, compared to composts, coconut coir, wood fiber and other alternative materials (Eymann et al., 2015). Including the costs of these environmental drawbacks in the costs of the substrate itself, could help making peat free substrates more popular.
In future studies, these assessments should be done simultaneously with the same substrates used in experiments as only then a complete picture can be generated. To do so, the development and evaluation will need to be done in a larger scope and taken to a broader level.

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