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WOOD FOAM APPLICATION IN GROWTH SUBSTRATE FORMULATION

Master's thesis (Double Degree Programme)

Natural Resources Management and Ecological Engineering, BOKU

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Abstract

There are economical and ecological concerns about utilizing peat as growth substrate and consequently a substitution is needed. Wood foam is a waste material and returning it to sustainable use is one of the main ecological tasks, besides, it has a good physical property-high water holding capacity. Therefore, the objective of this work was to research if wood foam is suitable as substitute for peat in potting media. For this, a pot experiment was conducted in the greenhouse with subsequent laboratory analysis to evaluate physical, chemical and some biological properties of the substrates. Five growth substrates were used including two target substrates where wood foam was amended in different proportions, to check the suitability in comparison with commercially available substrates. Two species, *Tropaeolum nanum* and *Lolium perenne*, were grown on the substrates and their performance evaluated. The growth experiment showed that wood foam is not suitable to substitute peat: the biomass was the lowest, fungal growth and compaction of the substrate were observed. However, total heavy metal concentrations of substrates comply with legal thresholds of Austrian compost standards and total element concentrations in plant tissue were within the optimal ranges.

In conclusion, wood foam cannot be used directly, but composting may be an alternative option to avoid waste formation.

Zusammenfassung

Wirtschaftliche und ökologische Probleme der Torfnutzung als Substrat für den Gartenbau erfordern die Suche nach Alternativen. Holzschaum, ein Reststoff aus der Verarbeitung neuartiger Materialien aus nachwachsenden Rohstoffen kommt aufgrund seiner Eigenschaften grundsätzlich in Frage Das Ziel der vorliegenden Arbeit war also die Untersuchung von Holzschaum als Torfersatz in Pflanzsubstraten. Zur Bewertung wurden zwei Substratgemische mit unterschiedlichen Anteilen an Holzschaum mit einer auf Torf basierenden Standardsubstratmischung und zwei kommerziell erzeugten Substraten hinsichtlich ihrer physikalischen, chemischen und biologischen Eigenschaften analysiert und im Gefäßversuch an zwei Pflanzenarten (*Tropaeolum nanum* und *Lolium perenne*) getestet. Aufgrund der Instabilität des Holzschaums unter Wassereinwirkung kam es in den Holzschaumsubstraten zu Verdichtungserscheinungen, Pilzwachstum an der Substratoberfläche sowie zu reduzierter Keimfähigkeit und Biomasseentwicklung der getesteten Pflanzen.

Obwohl die Nährstoff- und Schwermetallgehalte der Holzschaumsubstrate durchaus im optimalen bzw. gemäß Kompostverordnung akzeptablen Bereich lagen, erscheint die direkte Verwendung von Holzschaum als Torfersatz in Pflanzensubstraten daher nicht geeignet. Als mögliche Alternative kommt eine vorherige Kompostierung in Frage und sollte in weiteren Untersuchungen geprüft werden.

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1. Introduction

The worldwide consumption of commodities from wood will rise on 45% in 2020 according to the FAO forecast. Thus, it means that global forest will be under the additional pressure (FAO, 2001). Therefore, there is a need in sustainable production systems (Eshun et al., 2012). Nowadays, one of the main strategic goals in Europe is to increase appropriateness and utilization of wood by-products by regeneration of wood from treatment and end life products (Daian and Ozarska, 2009). It is generally accepted that restored wood ensures a high resource capacity for recycled products and innovative materials, forward increasing the environmental profile of wood (Daian and Ozarska, 2009).

At the University of Natural Resources and Life Sciences, Vienna, the Institute of Wood Technology is currently developing a novel, so called wood foam material. Wood foam is made of wood powder (sawdust) and wheat meal.

There are economical and ecological concerns about utilizing peat, therefore there is a need for alternative materials in commercial growing media (Bachman and Metzger, 2007). Combining these two rationales, sustainable wood waste recycling and the need for peat substitutes in potting substrates, I investigated if wood foam is suitable as component of potting mixes for horticulture.

Physical and Chemical Properties of wood foam

The suitability of a substrate for horticultural use depends on the performance of plants grown in it, consequently a harvest is better in a high quality substrate with a good physical and chemical characteristics (Verdonck and Gabriels, 1988).

Initial research was conducted on the wood foam properties by the Institute of Soil Research at the University of Natural Resources and Life Sciences, Vienna. Data from analysis are:

- Water holding capacity 146 vol-%;
- pH (H_2O) 5,17;
- pH ($CaCl_2$) 4,96;
- EC 0.677 ($mS \cdot cm^{-1}$).

Cation exchange capacity (CEC) in wood foam is represented in Table 1 with verbal assessment relatively to typical soil values.

Table 1: Cation exchange capacity (CEC) of wood foam in comparison with typical CEC values in soil

Element	CEC ($mmol_c \cdot kg^{-1}$)	Evaluation
Na	1.53	Slightly increased
Mg	9.66	Slightly increased
Al	0.06	Low
K	12.0	Very high
Ca	21.8	Normal
CEC	45.0	Low

Alternatives for peat replacement

Peat is a most common growth media and a non-renewable resource. Various organic materials have been studied to identify their acceptability for peat substitution in growth substrates in horticulture due to ecological concerns about peat bogs destruction (Marfa et al., 2002).

A literature review revealed different works aiming at partial or complete substitution of peat. Most of them consider municipal waste, sewage sludge, and waste from agro industry. And usually these are applied as compost and vermicompost in substrates. In Table 2 there are ranges of some physicochemical characteristics of various substrates commonly used in growth substrate formulation.

Table 2: Physicochemical characteristics of different organic substrates commonly used in potting (growth) substrate formulation

Physicochemical characteristics	Peat	Wood bark	Wood chips (fiber)		Coconut fiber (coir)	Sewage sludge compost	Spent mushroom compost	Municipal solid waste compost
CEC ($cmol \cdot kg^{-1}$)	10.6-167.3[a]	40-80[1]	22[1a]		69.8-107[1b]	-	-	13.7-63.3[1e]
Bulk density ($g \cdot cm^{-3}$)	0.07-0.17[b]	0.1-0.3[2]	0.07-0.15[2a]		0.057-0.1[2b]	-	0.22-0.39[2d]	341 ($g \cdot l^{-1}$)[2e]
Water-holding capacity (%)	49-58[c]	32 [3]	26[3a]		56-66.1[3b]	-	31-58[3d]	48[3e]
pH	3.17-6.22[d]	4.1-6.5[4]	4.5-7.9[4a]		5.3-6.1[4b]	6.83-8.2[4c]	5.83-8.2[4d]	7.8-8.8[4e]
EC ($mS \cdot cm^{-1}$)	0.02-0.26[e]	0.1-2.3[5]	0.08-0.3[5a]		0.6-6.5[5b]	0.9-2.04[5c]	4-8.51[5d]	2.3-19.8[5e]
NH_4-$N_{av,fr}$ ($mg \cdot kg^{-1}$)	2-162.7[f]	0.02-50[6]	0.2[6a]		0.3-130[6b]	4300-5290[6c]	15[6d]	1479.5[6e]
NO_3- $N_{av,fr}$ ($mg \cdot kg^{-1}$)	3-11.4[g]	0-60[7]	0.2[7a]		0.1-40[7b]	0-30[7c]	89[7d]	85.9[7e]
$P_{av,fr}$ ($mg \cdot kg^{-1}$)	0.3-880[h]	4-1000[8]	0.1[8a]	0.6-2.6 ($mg \cdot l^{-1}$) [8a]	3-6[8b]	180-1300[8c]	6-515[8d]	466.2-1012[8e]
$K_{av,fr}$ ($mg \cdot kg^{-1}$)	0.6-160.9[i]	42-2208[9]	25[9a]	34.2-34.9($mg \cdot l^{-1}$)[9a]	173-271[9b]	1100-2780[9c]	872.6-4400[9d]	432-3816[9e]
$Ca_{av,fr}$ ($mg \cdot kg^{-1}$)	3-9.5[j]	34-4000[10]	40[10a]	4.8-11.2 ($mg \cdot l^{-1}$)[10a]	2-5[10b]	200[10c]	413-2390.3[10d]	605.2[10e]
$Mg_{av,fr}$ ($mg \cdot kg^{-1}$)	1-41.1[k]	6-1000[11]	6[11a]	1.5-8 ($mg \cdot l^{-1}$)[11a]	3-4[11b]	46[11c]	220-261.7[11d]	1072[11e]
$Na_{av,fr}$ ($mg \cdot kg^{-1}$)	5[l]	10-313[12]	20[12a]	7-22.8 ($mg \cdot l^{-1}$)[12a]	75-104[12b]	2490[12c]	272.7-511[12d]	-
$Fe_{av,fr}$ ($mg \cdot kg^{-1}$)	0.2[m]	0.5-1442[13]	0.4 [13a]		0.4[13b]	5500-9950[13c]	1.9-4000[13d]	-
$Mn_{av,fr}$ ($mg \cdot kg^{-1}$)	0.1-2[n]	0.6-201[14]	0.29[14a]		0.1[14b]	173-430[14c]	0.9-300[14d]	-
Zn_{tot}($mg \cdot kg^{-1}$)	8.36-23[o]	34-174[15]	-		0.01[15b]	634-2500[15c]	3.7-200[15d]	420-940[15e]
Cu_{tot}($mg \cdot kg^{-1}$)	0.94-20[p]	3.68-6[16]	-		0.008[16b]	139-1500[16c]	2.6-25[16d]	280-623[16e]
Ni_{tot}($mg \cdot kg^{-1}$)	0.74-3[r]	3.69-5[17]	-		-	15-600[17c]	6-7.5[17d]	50-92[17e]
Pb_{tot}($mg \cdot kg^{-1}$)	1.5-2[s]	2.11-3[18]	-		-	80-1500[18c]	2.5-4[18d]	170-555[18e]
Cd_{tot}($mg \cdot kg^{-1}$)	0.12-0.26[t]	3[19]	-		-	2.4-20[19c]	0.12-0.25[19d]	2-10[19e]
Cr_{tot}($mg \cdot kg^{-1}$)	0.69-1.8[u]	1.46-2.5[20]	-		-	20-2000[20c]	6-12[20d]	30-80.2[20e]

(a) Moldes et al. (2007), Abad et al. (2002), Benito et al. (2006); (b) Arenas et al. (2002), Chong (2008), Vaughn et al. (2011), Perez-Murcia et al. (2006); (c) Moldes et al. (2007), Chong (2008); (d) Abad et al. (2002), Moldes et al. (2007), Chong (2008), Arenas et al. (2002), Garcia-Gomez et al. (2002), Perez-Murcia et al. (2006); (e) Moldes et al. (2007), Chong (2008), Garcia-Gomez et al. (2002), Arenas et al. (2002), Abad et al. (2002), Perez-Murcia et al. (2006); (f) Chong (2008), Moldes et al. (2007); (g) Chong (2008), Moldes et al. (2007); (h) Chong (2008), Moldes et al. (2007), Herrera et al. (2008); (i) Chong (2008), Moldes et al. (2007); (j) Chong (2008), Moldes et al. (2007), Boldrin et al. (2010); (k) Chong (2008), Moldes et al. (2007); (l), (m)single value obtained from Chong (2008); (n)Chong (2008), Boldrin et al. (2010);(o) Moldes et al. (2007), Boldrin et al. (2010), Perez-Murcia et al. (2006); (p), (r) Moldes et al. (2007), Boldrin et al. (2010), Perez-Murcia et al. (2006); (s) Moldes et al. (2007), Perez-Murcia et al. (2006); (t) Boldrin et al. (2010), Perez-Murcia et al. (2006); (u) Moldes et al. (2007), Perez-Murcia et al. (2006), Boldrin et al. (2010);

(1) Verdonck (1983), Biamonte (1982), Cull (1981); (2) Warren et al. (2009), Chong (2008), Wilson (1983); (3) single value obtained from Chong (2008); (4) Warren et al. (2009), Cull (1981), Chong (2008), Verdonck (1983); (5) Chong (2008), Verdonck (1983), Warren et al. (2009); (6) Chong (2008), Watteau et al. (2011), Cull (1981); (7) Watteau et al. (2011), Chong (2008), Cull (1981); (8) Watteau et al.

(2011), Cull (1981), Chong (2008), Verdonck (1983), Warren et al. (2009); (9) Chong (2008), Cull (1981), Warren et al. (2009), Verdonck (1983); (10) Chong (2008), Watteau et al. (2011), Warren et al. (2009); (11) Watteau et al. (2011), Chong (2008), Cull (1981), Warren et al. (2009); (12) Chong (2008), Warren et al. (2009); (13) Chong (2008), Verdonck (1983), Watteau et al. (2011), Warren et al. (2009); (14) Chong (2008), Warren et al. (2009), Verdonck (1983); (15) Warren et al. (2009), Miranda et al. (2012), Verdonck (1983); (16) Miranda et al. (2012), Warren et al. (2009), Verdonck (1983); (17) Miranda et al. (2012), Verdonck (1983); (18) Miranda et al. (2012), Verdonck (1983); (19) single value obtained from Verdonck (1983); (20) Miranda et al. (2012), Verdonck (1983);

(1a) single value obtained from Domeno et al. (2010); (2a) Domeno et al. (2010), Chong (2008); (3a) single value obtained from Chong (2008); (4a) Lemaire et al. (1989), Domeno et al. (2010), Chong (2008); (5a) Lemaire et al. (1989), Domeno et al. (2010), Chong (2008); (6a), (7a) single value obtained from Chong (2008); (8a) Chong (2008), Domeno et al. (2010), Lemaire et al. (1989); (9a) Chong (2008), Lemaire et al. (1989), Domeno et al. (2010); (10a) Chong (2008), Lemaire et al. (1989), Domeno et al. (2010); (11a) Chong (2008), Domeno et al. (2010), Lemaire et al. (1989); (12a) (2008), Lemaire et al. (1989), Domeno et al. (2010); (13a), (14a)single value obtained from Chong (2008);

(1b) Abad et al. (2002), Domeno et al. (2010), Meerow (1994), Verdonck (1983); (2b) Hernandez-Apaolaza et al. (2005), Asiah et al. (2004), Domeno et al. (2010), Chong (2008); (3b) Chong (2008), Meerow (1994); (4b) Asiah et al. (2004), Chong (2008), Verdonck (1983), Domeno et al. (2010), Hernandez-Apaolaza et al. (2005); (5b) Verdonck (1983), Chong (2008), Hernandez-Apaolaza et al. (2005), Asiah et al. (2004), Domeno et al. (2010); (6b) Chong (2008), Meerow (1994), Verdonck (1983); (7b) Chong (2008), Meerow (1994), Verdonck (1983); (8b) Chong (2008), Meerow (1994); (9b) Chong (2008), Meerow (1994); (10b) Meerow (1994), Chong (2008); (11b) Chong (2008), Meerow (1994); (12b) Chong (2008), Meerow (1994); (13b) Chong (2008), Meerow (1994); (14b) Chong (2008), Meerow (1994); (15b) single value obtained from Hernandez-Apaolaza et al. (2005); (16b) single value obtained from Hernandez-Apaolaza et al. (2005);

(4c) Watteau et al. (2011), Perez-Murcia et al. (2006), Verdonck (1983), Debosz et al. (2002); (5c) Verdonck (1983), Perez-Murcia et al. (2006); (6c) Debosz et al. (2002), Watteau et al. (2011); (7c) Watteau et al. (2011), Debosz et al. (2002); (8c) Watteau et al. (2011), Verdonck (1983); (9c) Verdonck (1983), Debosz et al. (2002), Perez-Murcia et al. (2006); (10c), (11c) single value obtained from Watteau et al. (2011); (12c) single value obtained from Perez-Murcia et al. (2006); (13c) Verdonck (1983), Watteau et al. (2011); (14c) Perez-Murcia et al. (2006), Verdonck (1983); (15c) Perez-Murcia et al. (2006), Watteau et al. (2011), Verdonck (1983), Wilson (1983); (16c) Perez-Murcia et al. (2006), Verdonck (1983), Watteau et al. (2011), Debosz et al. (2002), Wilson (1983); (17c) Verdonck (1983), Perez-Murcia et al. (2006), Wilson (1983); (18c) Perez-Murcia et al. (2006), Watteau et al. (2011), Verdonck (1983), Wilson (1983); (19c) Debosz et al. (2002), Perez-Murcia et al. (2006), Verdonck (1983), Wilson (1983); (20c) Verdonck (1983), Perez-Murcia et al. (2006), Debosz et al. (2002), Wilson (1983);

(2d) Lemaire et al. (1985), Eudoxie et al. (2011), Chong (2008); (3d) Chong (2008), Riahi et al. (1998); (4d) Riahi et al. (1998), Eudoxie et al. (2011), Lemaire et al. (1985), Heuser et al. (2008), Chong (2008); (5d) Chong (2008), Lemaire et al. (1985), Riahi et al. (1998), Eudoxie et al. (2011); (6d), (7d) single value obtained from Chong (2008); (8d) Chong (2008), Heuser et al. (2008), Riahi et al. (1998), Eudoxie et al. (2011); (9d) Riahi et al. (1998), Chong (2008), Heuser et al. (2008), Eudoxie et al. (2011); (10d) Heuser et al. (2008), Chong (2008), Riahi et al. (1998); (11d) Chong (2008), Heuser et al. (2008), Riahi et al. (1998); (12d) Riahi et al. (1998), Chong (2008); (13d) Chong (2008), Riahi et al. (1998), Lemaire et al. (1985); (14d) Chong (2008), Riahi et al. (1998), Lemaire et al. (1985); (15d) Riahi et al. (1998), Lemaire et al. (1985); (16d) Riahi et al. (1998), Lemaire et al. (1985); (17d), (18d), (19d), (20d) range obtained from Lemaire et al. (1985);

(1e) Cull (1981), Moldes et al. (2007); (2e), (3e) single value obtained from Moldes et al. (2007); (4e) Rosen et al. (1993), Moldes et al. (2007), Cull (1981), Herrera et al. (2008); (5e) Moldes et al. (2007), Rosen et al. (1993), Herrera et al. (2008); (6e), (7e) single values obtained from Moldes et al. (2007); (8e) Moldes et al. (2007), Herrera et al. (2008); (9e) Herrera et al. (2008), Rosen et al. (1993), Moldes et al. (2007); (10e), (11e) single values obtained from Moldes et al. (2007); (15e) Herrera et al. (2008), Cull (1981), Moldes et al. (2007), Rosen et al. (1993); (16e) Herrera et al. (2008), Cull (1981), Moldes et al. (2007), Rosen et al. (1993); (17e) Herrera et al. (2008), Moldes et al. (2007), Cull (1981); (18e) Herrera et al. (2008), Moldes et al. (2007), Rosen et al. (1993), Cull (1981); (19e) Rosen et al. (1993), Moldes et al. (2007), Cull (1981), Herrera et al. (2008); (20e) Herrera et al. (2008), Moldes et al. (2007).

Since the materials described in the Table 2 are intended for peat replacement, we compare properties of these substrates with peat itself.

Bulk density and water holding capacity are the most important among physical properties. From the Table 2, coconut fiber has less bulk density than peat, whereas wood chips and some values of wood bark are in the range of peat bulk density, but compost values are revealed as with higher bulk density than peat. Water-holding capacity of coconut fiber is higher compare to peat, while values of wood bark and wood chips being significantly lower. Composts have similar water-holding capacity to peat.

All individual substrates in the Table 2 have lower CEC than peat with the exception of coconut fiber, which has values within the peat CEC range. The pH values of wood bark and coconut fiber are more similar to peat, whereas values of wood chips, sewage sludge compost, spent mushroom compost and municipal solid waste compost have higher pH values in the alkaline range.

The EC values of coconut fiber and municipal solid waste compost are higher than those of peat, and vary considerably within the range of each material (Table 2). Among all materials considered in the Table 2, the EC values of wood chips are closest to those of peat.

Ammonia concentration is the lowest in wood bark and wood chips whereas in coconut fiber it is more similar to peat. While sewage sludge compost has almost thirty times higher ammonia concentration than peat, ammonia in spent mushroom compost is similar to the range of ammonia concentrations in peat. Nitrate concentrations in spent mushroom and solid waste composts are considerably higher than in peat, with 89 $mg \cdot kg^{-1}$ and 85.9 $mg \cdot kg^{-1}$, respectively, compared to the 3-11.4 $mg \cdot kg^{-1}$ in peat.

Similar to ammonia, the concentration of phosphorus in sewage sludge compost and municipal waste compost are considerably higher than in peat.

All three composts have similar range of potassium concentrations and they are higher by several thousand $mg \cdot kg^{-1}$ than in peat. Whereas coconut fiber, wood bark and chips have more or less similar values of potassium compare to peat.

It is obvious from the Table 2 that wood bark, spent mushroom compost and municipal solid waste have the highest calcium and magnesium concentrations range, whereas peat and coconut fiber have very similar values. However, the highest sodium concentration is observed in sewage sludge compost which fifty times higher than in peat. Wood bark and chips, coconut fiber and sewage sludge compost have values of sodium slightly higher than peat. Iron concentration is considerably higher in sewage sludge compost compared to peat. For wood chips and coconut fiber we found in the literature only single values for iron and manganese concentrations that are very similar to peat. Manganese concentrations in wood bark and spent mushroom compost overlap with peat ranges but may also exceed the values in peat whereas sewage sludge typically has higher Mn concentrations compared to peat.

Zinc and copper concentrations in peat are in similar range according to the values in the Table 2. Coconut fiber has lower zinc and copper concentrations than peat. Zinc values in spent mushroom compost range within or exceed those of peat like in the case of manganese. Zinc and copper concentrations are quite higher in sewage sludge and solid waste composts compared with peat, for example to take zinc concentrations, 634-2500 $mg \cdot kg^{-1}$ and 420-940 $mg \cdot kg^{-1}$, respectively, versus 8.36-23 $mg \cdot kg^{-1}$ in peat. Copper values of wood bark and spent mushroom compost are within peat range, although some of the values are higher in mushroom compost.

Nickel and lead concentrations in all substrates compiled in the Table 2 are above those in peat; for wood and coconut fibers no data about metal concentrations are available. The highest Ni and Pb concentrations are found in sewage sludge and municipal solid waste composts. For instance, Pb in peat varies between 1.5 $mg \cdot kg^{-1}$ and 2 $mg \cdot kg^{-1}$ whereas in sewage sludge compost this element can range between 80 $mg \cdot kg^{-1}$ and 1500 $mg \cdot kg^{-1}$.

Cadmium concentrations in spent mushroom compost do not exceed those of peat (Table 2). All other substrates have higher values than peat. With regard to chromium, wood bark can have twice as high concentrations than found in peat, while sewage sludge compost, spent mushroom and solid waste composts have values that may considerably exceed the range of peat.

Based on the information discussed above it could be concluded that there is no single organic substrate among those considered in the Table 2 which would have all physicochemical properties similar to peat. Still these materials may have their own positive functions for potting substrate formulation as summarized in the Table 3.

Table 3: Main functions of individual components in potting substrate formulation

Component	Functions
Peat	Improving aeration, drainage, water and nutrient retention (Garcia-Gomez et al., 2002)
Wood bark	Increasing air porosity, drainage (Lennox et al., 1987), soil conditioning (Verdnock, 1983)
Wood chips (fiber)	Increasing air capacity (Domeno et al., 2011)
Coconut fiber (coir)	Increasing water holding capacity, very good drainage (Meerow, 1994) resistance to compression (Wever et al.,1995; Meerow, 1994)
Sewage sludge compost	Providing high nitrogen source (Watteau et al., 2011), increasing nutrient supply (Perez-Murcia et al., 2006)
Spent mushroom compost	Increasing nutritional supply (Eudoxie et al., 2011)
Municipal solid waste compost	Increasing water retention and the supply of essential nutrients (Herrera et al., 2008; Rosen et al., 1993, Raviv, 1998)

As indicated in the Table 3, wood bark and chips improve aeration, sewage sludge, spent mushroom and municipal solid waste composts provide nutrients for growth media, beside this function, solid waste compost as well as coconut fiber increase water holding capacity. Along with this, coconut fiber assists in drainage and to resist against compression.

To decide whether a substrate is acceptable for use in potting media one needs to know which properties are desirable for a mixture. The Table 4 compiles optimal and critical ranges for potting media.

Table 4: Optimal ranges for potting media

Physicochemical characteristics	Optimal and critical values	
CEC ($cmol \cdot kg^{-1}$)	-	
Bulk density ($g \cdot cm^{-3}$)	0.2-0.75[(1)]	
Water-holding capacity (%)	20-60[(2)]	
pH	5.3-7.0[(3)]	
EC ($mS \cdot cm^{-1}$)	≤10[(4)]	
C:N	20-40[(5)]	
NH_4-N ($mg \cdot kg^{-1}$)	≤1[(6)]	
NO_3-N ($mg \cdot kg^{-1}$)	100-200[(7)]	100-199 ($mg \cdot l^{-1}$)[(7)]
P ($mg \cdot kg^{-1}$)	6-9[(8)]	6-10 ($mg \cdot l^{-1}$)[(8)]
K ($mg \cdot kg^{-1}$)	150-200[(9)]	150-249 ($mg \cdot l^{-1}$)[(9)]
Ca ($mg \cdot kg^{-1}$)	200-300[(10)]	
Mg ($mg \cdot kg^{-1}$)	70-200[(11)]	
Na ($mg \cdot kg^{-1}$)	0-50[(12)]	
Fe ($mg \cdot kg^{-1}$)	0.3-3[(13)]	
Mn ($mg \cdot kg^{-1}$)	0.3-3[(14)]	
Zn ($mg \cdot kg^{-1}$)	200-1800[(15)]	
Cu ($mg \cdot kg^{-1}$)	70-500[(16)]	
Ni ($mg \cdot kg^{-1}$)	25-100[(17)]	
Pb ($mg \cdot kg^{-1}$)	45-200[(18)]	
Cd ($mg \cdot kg^{-1}$)	0.7-3[(19)]	
Cr ($mg \cdot kg^{-1}$)	70-250[(20)]	

(1) Abad et l.(2001), Chong (2008); (2) Chong (2008), Rynk et al.(1992); (3) Abad et al. (1993), Chong (2008); (4) Abad et al. (1993), Milks et al. (1989), Chong (2008); (5) Abad et al. (1993); (6) single value obtained from Chong (2008); (7) Chong (2008), Abad et al. (1993); (8) Chong (2008), Abad et al. (1992); (9) Chong (2008), Abad et al. (1992); (10), (11), (12), (13), (14) single value obtained from Chong (2008); (15), (16), (17), (18), (19), (20) heavy metals limits for compost standards in Austria. Values obtained from Amlinger et al. (2004).

If we compare data from the Table 2 with the optimal ranges for physicochemical characteristics of different substrates provided in the Table 4, we can derive which substrate is better for peat substitution.

Bulk density and water holding capacity values of wood bark and chips, coconut fiber and three composts are all in the range of optimal values (20-60%), however, coconut fiber may even exceed this range with values up to 66.1%.

For pH, coconut fiber is the best in fitting the optimal range while values found for wood bark and chips, sewage sludge and spent mushroom composts are lower or higher than the optimum range; pH values reported for municipal solid waste compost generally exceed the desirable range. All substrates listed in the Table 2 are within the optimal range of EC (<10 $mS \cdot cm^{-1}$).

For ammonia concentrations only wood chips, wood fiber and coconut fiber meet the desirable range, while composts significantly exceed the optimum. On the other hand, nitrate concentrations of the substrates are typically below the desirable range. Phosphorus concentrations are noticeably higher in all substrates than considered as optimal range, only wood fiber and coir have lower values than desired. Potassium concentrations in coconut fiber closely fit to the optimum range whereas wood fiber has significantly lower K concentrations. Wood chips and coconut fiber as peat have lower calcium and magnesium concentrations than the desirable values, but sewage sludge compost has also lower magnesium concentrations. Iron and manganese concentrations in wood fiber, bark and coir are within the optimum range, while they are greatly higher in composts.

Heavy metals concentrations in the Table 4 are listed for compost standards in Austria.

To sum up, the ranges of different characteristics for each substrate may vary significantly and some values fit to values of peat and optimal ranges. From above discussion, it could be seen that coconut fiber usually has values, which are very similar to peat and acceptable for growth media.

Research objective

This master thesis forms part of a research project that explores wood foam application in growth substrate formulation and compares it with commercial substrate. Its main objective was to assess whether wood foam was suitable as peat substitute in potting media. For this, the tests included mixes of the wood foam granulates with other materials such as vermiculate, compost for production a full growth substrate. Substrates should have physical and chemical properties favorable for plant growth and be uniform, consistent, light weight, affordable (Moore, 2005, Morelock, 1980), and absent of viable seeds and harmful pathogens (Handreck and Black, 2002). Selection of eligible potting substrate is an important step to satisfy the demands for growth of healthy plants (Jackson, 2005).

Therefore, the aim was to determine the physical, chemical and some biological properties of the full growth substrates in the laboratory and perform a greenhouse experiment to check the suitability in comparison with commercially available substrates. To this end, two species, *Tropaeolum nanum* and *Lolium perenne*, were used in this work to determine their growth response to wood foam substrates in comparison with home-made and commercially available potting media.

2. Materials and Methods

2.1 Set-up of the plant experiment

The experiment was carried out in the greenhouse at the University of Natural Resources and Life Sciences, Vienna. Climate conditions were automatically controlled, with air temperature maintained at 22ºC and 14 hours of light.

The experiment was set up according to the following plan using 0.5 kg of substrate per pot, with four replicates:

- Mix 1: vermiculite 20% (v/v), compost 50% and peat 30%;
- Mix 2: vermiculite 20%, compost 50% and wood foam 30%;
- Mix 3: vermiculite 20%, compost 70% and wood foam 10%;
- Commercial substrate;
- 'Grand substrate'.

Wood foam was received from the Institute of Wood Technology of the University of Natural Resources and Life Sciences, Vienna.

Surfaces of pots were covered with polypropylene films. The weight of each substrate per pot was measured. Bulk density was determined by dividing mass of the substrate by volume of the pot.

Two plant species were used, Nasturtium (*Tropaeolum nanum),* in amount of 3 seeds per pot, and ryegrass (*Lolium perenne)* by weighting 0.5 g per each pot, in all substrates, and mixes 1, 2 and 3 were also exposed to the greenhouse conditions without plants (Table 5). All treatments were run in four replicates, thus in total, there were 52 pots (Figure 1).

Table 5: Schematic illustration of the pot experiment

Substrate	Nasturtium *(Tropaeolum nanum)*	Ryegrass *(Loliumperenne)*	No plant
Mix 1 (M1)	M1K	M1L	M1N
Mix 2 (M2)	M2K	M2L	M2N
Mix 3 (M3)	M3K	M3L	M3N
Commercial substrate (CS)	CSK	CSL	-
Grand substrate (G)	GK	GL	-

During plant growing period photo documentation was performed for tracing plant performance (including nutrition and toxicity signs) and description of substrate surface with the emphasis on fungal growth.

Figure 1: Set-up of the experiment

The samples were watered three times per week. The total duration of the pot experiment was 32 days, from January 11, 2013.

2.2 Nature and origin of the substrates

Commercial substrate: Mixture of bark, wood fibers, green waste compost, sand and mineral NPK fertilizer.

Salinity (KCl): <3.0 $g \cdot L^{-1}$
pH ($CaCl_2$): 5.5-7.0
Available nutrients: 60-400 $mg \cdot L^{-1}$ N ($CaCl_2$)
80-700 $mg \cdot L^{-1}$ P_2O_5 (CAL)
200-1300 $mg \cdot L^{-1}$ K_2O (CAL)
Producing country: Austria

Grand substrate (Vermigrand peat - free organic soil):
Components:

- Wagramkompost
- Lavasand (Hephalit, Austria)
- Bark compost (Austrian resources)
- Worm biohumus (vermicompost)
- Biochar (wood from Austria)

Quality: certification for use in organic agriculture (Austrian Bio Guarantee, ABG, Österreichisches Umweltzeichen - Austrian Ecolabel, approval for specific use from Austrian Agency for Health and Food Safety, AGES).

Compost (Wagramkompost):
Composting materials: Alfalfa hay (lucerne) and horse manure. All ingredients are certified organic. Quality: The compost is a grade A+ compost and usable for organic agriculture.
Grand substrate and compost were received from Mr. Alfred Grand (VERMIGRAND Naturprodukte GmbH).

2.3 Laboratory analysis

After the pot experiment plants were harvested and their biomass production assessed. Meanwhile, each substrate was put into appropriate plastic bags.

The above ground plant parts were cut off at the soil surface and roots were washed carefully with tap water from the attached soil. Plant and root biomass was determined fresh and after drying for 48 h at 80°C.

Nutrients and metals in plant tissues. Shoot and root samples were prepared for the microwave digestion by grinding tissues on a special equipment (IKA A11 basic analytical mill). Plant tissues were weighted in amount of 20 mg and 0.5 ml HNO_3 and 0.1 ml H_2O_2 were added for digestion, which was performed on a Rotor 64MG5 for Synthos 3000, Anton Paar. After the digestion the extracts were filtered through syringe filters (Rotalibo-Spritzenfilter, ROTH, Nylon-Membrane, 0.20 µm) for determination of nutrients and potential pollutants with ICP-MS.

Electrical conductivity (EC) and pH. pH of substrates were measured in mixtures of 10 g soil with 25 ml solution, the first was deionized water (Millipore) water and the second was 0.01 M $CaCl_2$, according to ÖNORM L1083-89, which were shaken by hand, left to equilibration for 2 h and shaken again and left to settle the substrate to the bottom. Afterwards the pH was measured with Thermo Scientific benchtop pH meter. The calibration was checked every 10 samples, using buffer solution 7. EC was measured in the same solution with deionized water after pH measurement and filtration (Munktell Folded Filters with grade: 14/N, diameter: 150 mm, 80 $g \cdot m^{-2}$). This filter paper was used during all filtration in experiments of this work. And afterwards, EC was measured with inoLab Terminal 740, WTW series.

Water holding capacity. Ten g of soil was put into funnel with filter paper and properly saturated with water. The funnels were covered with foil and left overnight for drainage under gravity. Afterwards mass of saturated soil was determined and after drying at 105ºC for 24 h.

Soil water content. Ten g of soil was weighted fresh and reweighted again after ovendrying at 105ºC for 48 h. The data was used for calculations in the following experiments to convert results to oven-dried mass.

Cation exchange capacity (CEC) and exchangeable cations. 0.1 M $BaCl_2$ solution was used as reagent (ÖNORM L1086-89, modified). The sieved soil (<2mm) samples were mixed in a ratio of 1:20 (w:v) with the solution. The samples were manually shaken and left overnight and on the next day shaken end-over-end for 2 h at 20 revolutions per minute at room temperature. Thereafter they were allowed to settle for 15 min and filtered. One ml of nitric acid, HNO_3 (65%), was added to the filtered samples to obtain 1% acid-solutions for stabilizing until analysis by ICP-MS.

Mineral nitrogen. Soil samples were mixed in a ratio of 1:4 (w:v) with 0.0125 M $CaCl_2$, shaken for 2 h and then filtered. Nitrogen was analyzed by determining ammonium (NH_4^+-N) and nitrate (NO_3^--N) in the prepared extractions. Chemicals used for:

- ammonium determination: Sodium nitroprusside dehydrate, Sodium salicylate, Dichloroisocyanuric acid, Sodium hydroxide pellets, Ammonium chloride;
- nitrate determination: Hydrochloric acid 32%; Vanadium(III) chloride; N-(1-Naphthyl)ethylenediaminedihydrochloride; Sulfanilic acid; Potassium nitrate.

The microtiter plate for ammonium measurements completely filled with set of samples was shaken and incubated at 25°C for 30 minutes. Then the microtiter plate was measured at 660 nm. The microtiter plate for nitrate measurements completely filled with set of samples was incubated at 37°C for 30 minutes. Then the microtiter plate was measured at 540 nm. Measurements were performed by microtiter plate reader (Perkin Elmer EnSpire 2300 Multilabel Reader).

Phosphorus and potassium. Determination of plant-available phosphate and potassium was done by calcium-lactate method (CAL, ÖNORM L1087). 77 g of calcium lactate and 39.5 g of calcium acetate were dissolved in 600 ml hot deionized water. After dissolving 89.5 ml acetic acid was added and the solution was filled up to 1000 ml. This stock solution was diluted in a ratio of 1:5-CAL - work-solution. CAL-work-solution was added to the sieved soil (<2mm) samples in a ratio of 1:20 (w:v). Then the mixes were shaken end-over-end for 2 h at 20 revolutions per minute at room temperature, after that settled for 15 min, filtered and measured on ICP-OES.

Micronutrients. For determination of micronutrients in soil samples 0.05 M Na_2EDTA was used in a soil: solution ratio of 1:10 (w:v). After 2 hours extraction and shaking end-over-end at 20 revolutions per minute at room temperature, the samples were filtered. The measurements were done on ICP-MS.

Metals in 1 M NH_4NO_3. Substrates were mixed with 1M NH_4NO_3 solution in a ratio of 1:2.5 (w:v) according to DIN V 19730. The samples were shaken end-over-end for 2 h at 20 revolutions per minute at room temperature, then settled for 15 min and filtered.

Nitric acid, HNO_3 (65%), was added to the filtered samples to obtain 1% acid-solutions for stabilizing until analysis by ICP-MS.

For the following two measurements, CN(S) total analysis and total element composition, subsamples of each substrate were oven-dried at 105ºC for 48 h and subsequently ground in a ball mill and homogenized.

Total element composition determination was conducted using soil digestion method with *aqua regia* using 0.5 g of soil (ÖNORM L1085). 4.5 ml of HCl and then 1.5 ml of HNO_3 were added in this order and one drop of octanol to inhibit foaming. The tubes with coolers were left to react overnight. The following day with the samples were heated to 150ºC for 3 hours. Deionized water was added to obtain about 50 ml samples and each tube was mixed using vortex-shaker (Heidolph Reax top) and filtered for the consecutive analysis on ICP-MS.

CN(S) total analysis. Total concentrations of C, N and S were determined using an instrumental combustion technique (Vario EL, Elementar Analyse systeme GmbH).

Cress test. A cress test (fig. 2) was conducted for one week on the initial five substrates: mix 1, mix 2, mix 3, commercial substrate, Grand substrate; in three replicates, with seeding Cress (*Lepidium sativum)* in amount of 30 seeds per pot. In addition, one control sample was sown in a Petri dish on a wet tissue paper. After one week the germination rate was calculated by counting the number of germinated seeds and determination of fresh and dry biomass after 48 h at 80°C.

Figure 2: Set-up of the cress test

Accuracy of measurements

Three blanks with corresponding solution and three reference materials (Moosbierbaum) were included in each measurement series for the analysis on ICP-OES, ICP-MS and microtiter plate reader to ensure a quality control. Also, measurements of one blank and one quality control were implemented in each twenty samples on ICP-MS and ICP-OES in order to monitor deviations from the calibration standards of the equipment.

Statistics

Treatment means and standard errors (SE) were displayed in the graphs and tables of the result section.

One-way ANOVA test was performed to evaluate the statistical differences between the five substrates (M1, M2, M3, CS, G) before the pot experiment.

Two-way ANOVA test was used to evaluate the significance of two factors: plant (nasturtium and ryegrass) and substrate, and their interaction after the pot experiment. As zero hypothesis ($\alpha=0.05$) was assumed that all factors had no significant influence. In the case the significance of the factor was revealed, after ANOVA test, post hoc Tukey's-b test was used to evaluate significant differences between individual means except for the plant factor due to there were fewer than three groups.

Statistical analyses were performed by SPSS software (version 16.0) by comparing means with One-way ANOVA and General Linear Model (univariate and multivariate).

The resumes of ANOVA tests are presented in the Annex (A1-A25), post hoc results are included in the figures and tables of the results and discussion section.

3. Results and discussion

3.1 Plant growth

At the end of the growth experiment, the plant performance was as shown in the Figure 3.

Figure 3: Results of plant growth in the greenhouse

During plant growth, fungal growth was observed on the surfaces of the treatments with mix 2 where wood foam was applied in the highest amount (Fig. 4).

Mix 2 with no plant

Mix 2 with ryegrass

Mix 2 with Nasturtium

Mix 3 with no plant

Mix 3 with ryegrass

Mix 3 with Nasturtium

Figure 4: Comparison of substrate surfaces of mixes 2 and 3

In contrast to pots with mix 3, all surfaces of treatments with mix 2 were covered with white layer, which was considered as fungi. The high levels of mineral nutrients, especially nitrogen, and lack of drainage are the reasons for fungal growth (Landis, 1990). The pH can also influence different microorganisms, including fungal pathogens. For instance, *Fusarium* spp. are more virulent in neutral to alkaline conditions (Handreck and Black 1984).

The weight of dry shoots and roots of Nasturtium (K) and ryegrass (L) are displayed in the Figure 5.

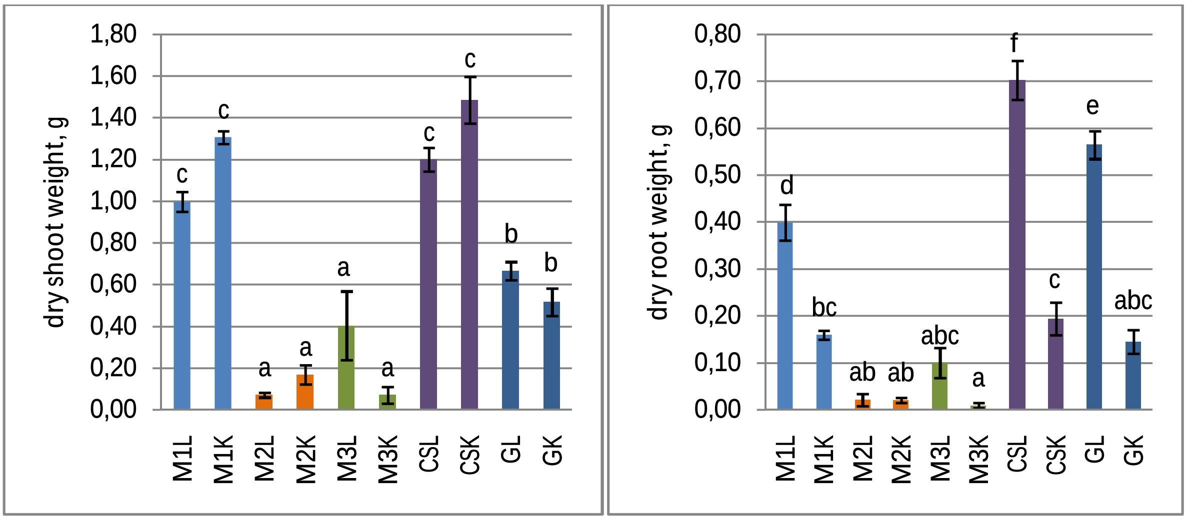

Figure 5: Dry shoot and root biomass (with standard error, n=4, in M2K, M3K and CSK n=3 due to absence of germination in each subsample). Two-way ANOVA revealed significance ($p<0.05$) of the substrate factor in dry shoots; substrate, plant and their interaction factors in dry roots. Means with the same letter above the bar are not significantly different according to Tukey's-b test ($\alpha=0.05$).

The highest dry shoot biomass was produced in the commercial substrate, where the weight was slightly higher than in mix 1 with peat, whereas the lowest biomass of dry shoots was found in mixes 2 and 3 with wood foam. The same tendency was found in dry root weight, though dry root mass was higher in the Grand substrate than in mix 1. It can be noticed that dry root weight of ryegrass was heavier than that of Nasturtium.

Cress test. The cress test revealed a similar trend: the greatest dry cress weight was in mix 1 and commercial substrate while mixes 2 and 3 had the lowest biomass (Fig. 6 and 8).

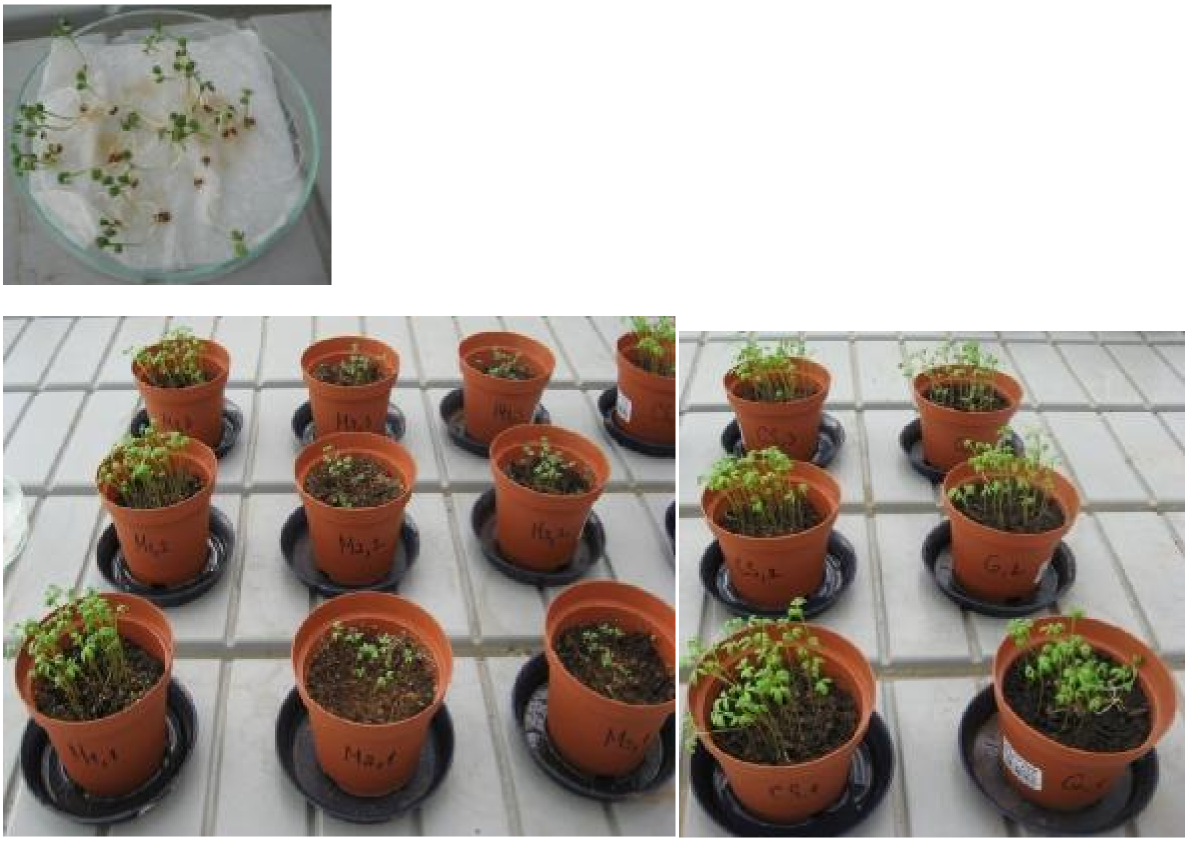

Figure 6: Cress test results (from left to the right: mix 1, mix 2, mix 3, commercial substrate and Grand substrate)

Figure 7 shows that all 30 seeds were germinated in control sample in a petri dish. Whereas mixes 2 and 3 had the lowest germination rate, while mix 1, commercial and Grand substrates showed average germination of 26-27 seeds from 30.

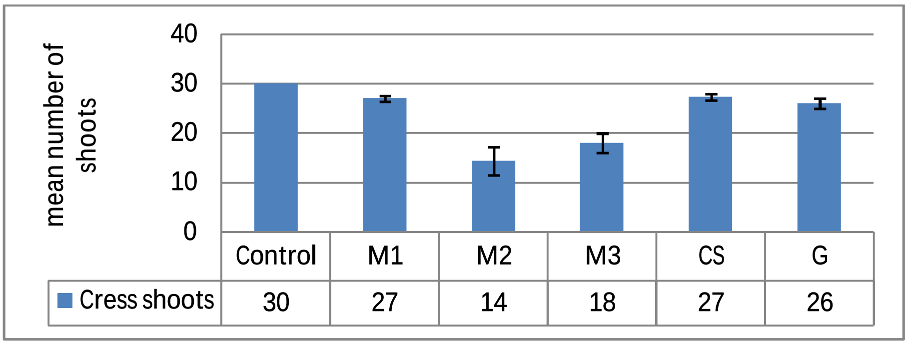

Figure 7: Average cress germination rate (with standard error, n=3)

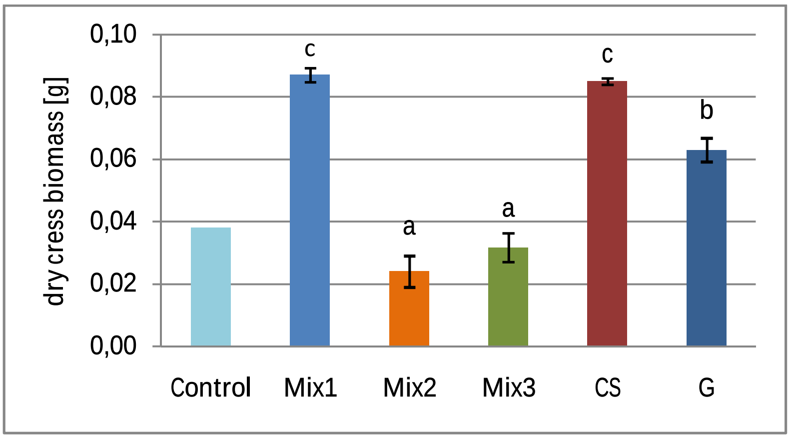

Figure 8: Cress dry weight (with standard error, n=3). One-way ANOVA revealed significance ($p=0.000$) of the substrate factor. Means with the same letter above the bar are not significantly different according to Tukey's-b test ($\alpha=0.05$).

From the above graphs it could be said, that a main reason of low cress biomass in mixes 2 and 3 with wood foam is low germination rate.

3.2 Growth media characteristics

For evaluation of substrate suitability as growth media physicochemical properties were measured.

Bulk density and water holding capacity. Figure 9 shows that the lowest bulk density was in commercial substrate, mix 2 had lower bulk density compared to mix 1 with peat and mix 3 with lower amount of wood foam. The highest bulk density was revealed in Grand substrate. However, all values of bulk density before the pot experiment were within the optimal range for growth media (0.2-0.75 g·cm^{-3}, Table 4). After the pot experiment the volume of all substrates decreased slightly resulting in increased bulk density.

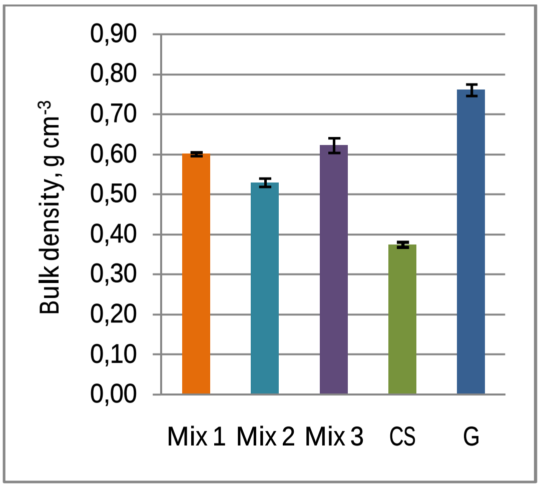

Figure 9: Bulk density of five substrates before the pot experiment (with standard error, n=4). One-way ANOVA revealed significance ($p<0.05$) of the substrate factor.

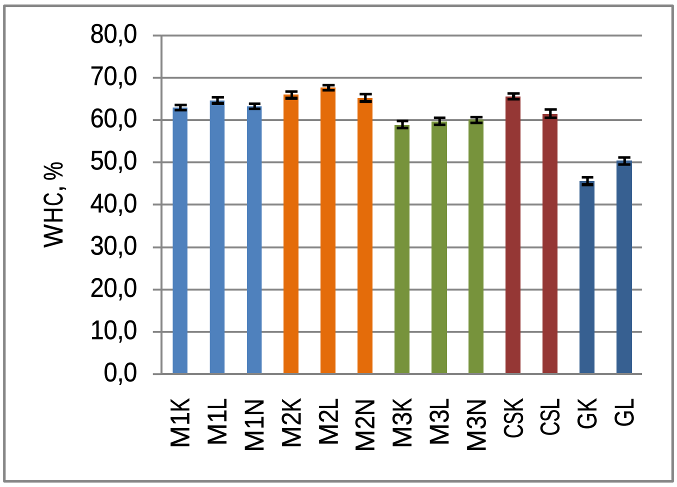

Figure 10: Water holding capacity (with standard error, n=4) after the pot experiment. Two-way ANOVA revealed significance ($p<0.05$) of the substrate, plant and their interaction factors.

Figure 10 demonstrates that the average water holding capacity in mixes 1, 2 and 3 and in commercial substrate was in the range of 59-67%, and mix 2 had the highest values, while Grand substrate had the lowest WHC, at around 50%. As bulk density, WHC of all substrates was in the optimal range (20-60%, Table 4) or even slightly above.

pH measurements showed that pH was lower in all substrates before the experiment compared to the values after the experiment (Fig. 11). Generally, the trends of pH were similar for four substrates with only exception of Grand substrate: pH in water solution before the experiment was the highest (8.77), while in calcium cloride it was lower than that of mix 1. After the experiment the highest pH ($CaCl_2$) was found in mix 3 where values were above 8.0, which corresponds to moderately alkaline, whereas all other substrates were slightly alkaline, in the range of 7.56-7.9. Before the experiment pH of all substrates ranged between 6.83-7.53, and these values are higher than optimal range, 5.4-7.0, except for the commercial substrate.

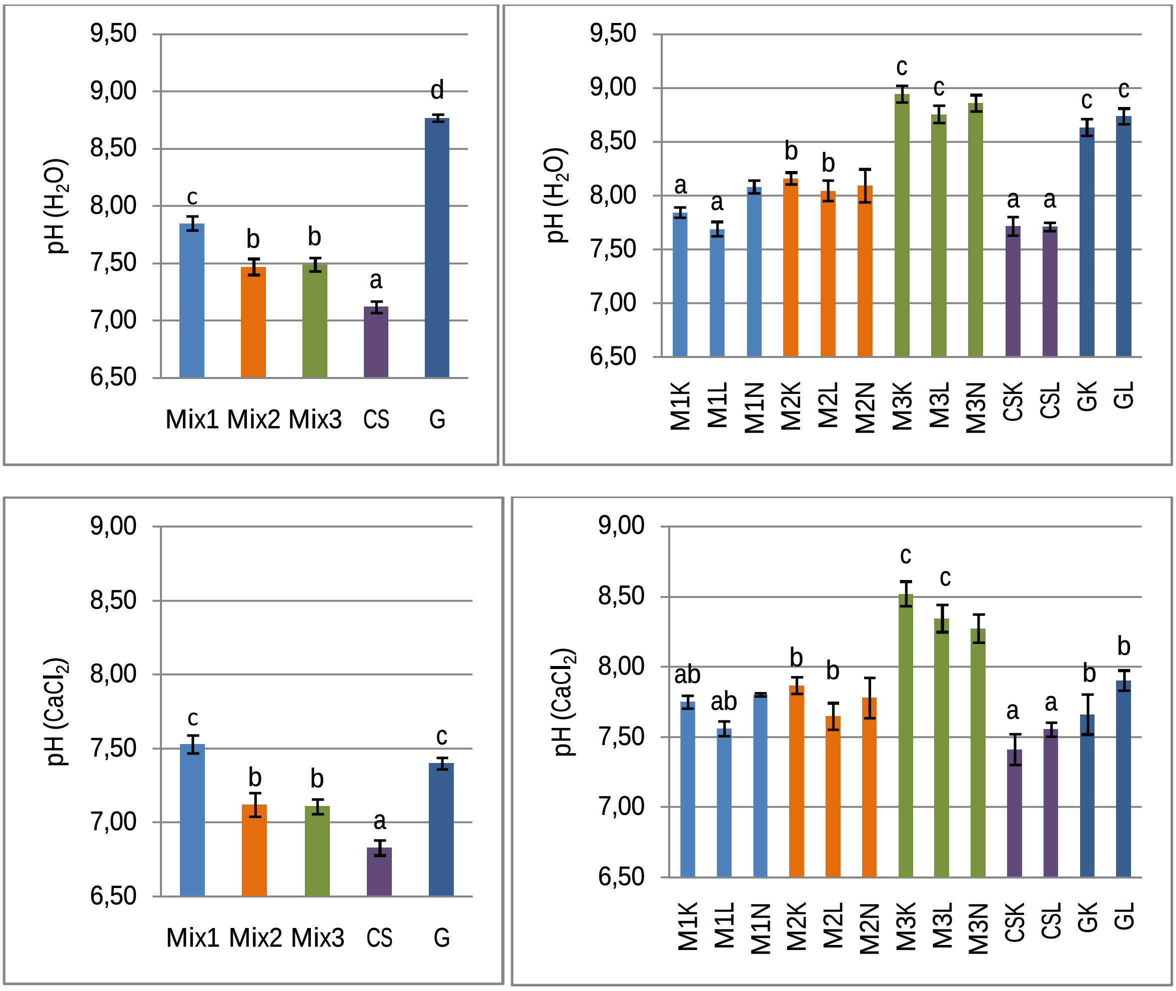

Figure 11: pH in water and 0.01M calcium cloride solutions (with standard error, n=4). On the left pH before the experiment is shown. One-way ANOVA revealed significance (p=0.000) of the substrate factor. The right side shows pH after the experiment. Two-way ANOVA revealed significance (p<0.05) of the substrate factor. Means with the same letter above the bar are not significantly different according to Tukey's-b test (α=0.05).

EC before plant growth was the lowest in Grand substrate and the highest one in mix 3 (Fig. 12). Overall, EC values were in the optimal range (below 10 mS·cm^{-1}, Table 4). At the end of the experiment, EC decreased in mix 2, mix 3 and the commercial substrate. On the contrary, EC increased in the Grand substrate and in planted mix 1 treatments, but dropped in the non-planted mix 1.

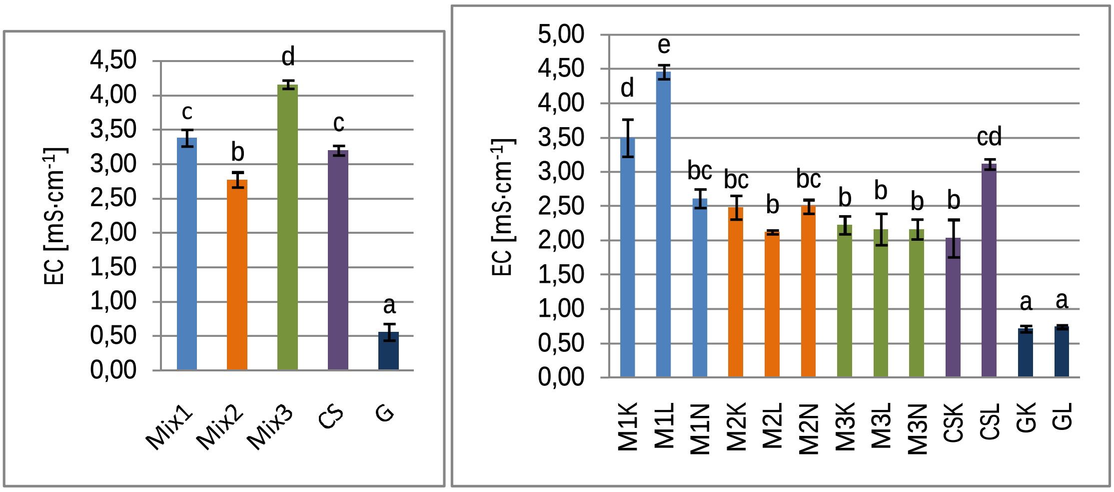

Figure 12: EC (with standard error, n=4). On the left EC before the experiment is shown. One-way ANOVA revealed significance (p=0.000) of the substrate factor. The right side shows EC after the experiment. Two-way ANOVA revealed significance ($p<0.05$) of the substrate, plant and their interaction factors. Means with the same letter above the bar are not significantly different according to Tukey's-b test (α=0.05).

CNS total analysis. Table 6 and 7 show data of total nitrogen, carbon and sulfur content and C to N ratio in the substrates before and after the experiment, respectively. The ideal substrate C/N ratio should be in the range of 20-40 (Table 4).

Table 6: Total nitrogen, carbon, sulfur content before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	N%	C%	S%	C:N
Mix1	1.09±0.02 c	15.3±0.36 b	0.25±0.01 a	13.9±0.26 a
Mix2	1.08±0.04 c	25.7±0.68 d	0.27±0.02 ab	23.7±0.34 c
Mix3	1.04±0.02 c	17.3±0.42 c	0.23±0.00 a	16.6±0.38 b
Commercial substrate	0.76±0.02 b	18.7±0.39 c	0.33±0.03 b	24.5±0.62 cd
Grand substrate	0.49±0.01 a	12.5±0.51 a	0.20±0.01 a	25.6±0.31 d

Table 7: Total nitrogen, carbon, sulfur content at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	N%	C%	S%	C:N
M1K	1.03±0.01c	14.9±0.14a	0.31±0.00c	14.4±0.14 a
M1L	1.03±0.02c	14.5±0.21a	0.31±0.01c	14.1±0.03 a
M1N	1.03±0.04	14.8±0.46	0.31±0.02	14.4±0.10
M2K	1.05±0.04c	18.8±0.62d	0.25±0.01b	18.0±0.65 b
M2L	1.10±0.02c	20.3±0.30d	0.25±0.00b	18.4±0.31 b
M2N	1.15±0.04	20.2±0.83	0.27±0.01	17.6±0.42
M3K	1.06±0.03c	15.9±0.32b	0.25±0.00 b	15.0±0.30 a
M3L	1.06±0.02c	15.8±0.38b	0.26±0.00b	14.9±0.27 a
M3N	1.04±0.02	16.0±0.28	0.27±0.00	15.4±0.34
CSK	0.77±0.03b	18.0±1.00c	0.40±0.03d	23.5±0.56c
CSL	0.75±0.01b	16.4±0.16c	0.43±0.02d	21.8±0.19c
GK	0.55±0.01a	14.0±0.19 a	0.19±0.02a	25.2±0.46d
GL	0.54±0.02a	13.9±0.64a	0.15±0.00a	25.6±0.34d

Among all treatments only the commercial and Grand substrates had appropriate C/N ratio, which was above 20. Iinitially, mix 2 with wood foam had also suitable C/N ratio, but decreased during the experiment, whereas mixes 1 and 3 had low values.

Cation exchange capacity. High CEC in the substrates is beneficial due to higher absorption and exchange capacity for nutrients. According to Tables 8 and 9, generally, the CEC slightly decreased in mixes 1, 2 and 3 during the experiment. The highest CEC among the five different substrates was observed in mix 1 containing peat, whereas mix 3 and the commercial substrate had a total CEC of about 100 $mmol_c \cdot kg^{-1}$ lower than in mix 1. The lowest CEC was found in the Grand substrate.

Table 8: CEC ($mmol_c \cdot kg^{-1}$) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Na^+	Mg^{2+}	Al^{3+}	K^+	Ca^{2+}	Total CEC
Mix1	23.1±0.52 d	226±2.45 e	0.04±0.02 a	341±4.23 d	296±6.38 b	886±10.4 d
Mix2	17.7±0.60 b	193±3.09 d	0.12±0.00 b	265±3.95 c	192±4.45 a	668±11.3 b
Mix3	22.6±0.49 cd	171±3.21 c	0.29±0.03 c	360±4.20 e	214±7.51 a	767±8.45 c
Commercial s.	9.34±0.33 a	109±4.25 b	0.03±0.00 a	75.2±2.86 a	562±11.7 c	755±12.8 c
Grand s.	21.9±0.64 c	85.7±3.86 a	0.01±0.00 a	128±4.62 b	280±6.37 b	516±12.3a

Table 9: CEC ($mmol_c \cdot kg^{-1}$) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate, plant factors, except for Ca and Al: plant-factor has no significance; significance of the interaction substrate*plant factor for Mg, Ca. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Na^+	Mg^{2+}	Al^{3+}	K^+	Ca^{2+}	Total CEC
M1K	27.9±0.50 cd	246±1.23 g	0.24±0.01c	322±2.90 ef	354±6.17c	951±7.81 h
M1L	27.6±0.75 cd	223±2.68 f	0.09±0.00c	301±5.53 de	331±4.78c	883±6.82 g
M1N	28.1±0.64 cd	215±2.11 f	0.16±0.00	348±5.30 f	286±7.74	877±11.0 g
M2K	27.3±0.57 cd	194±4.69 de	0.16±0.00b	290±7.42 de	179±6.06a	691±9.70 cd
M2L	23.6±0.68 b	161±6.49 c	0.05±0.00b	248±3.68 c	202±5.67 a	634±8.86 abc
M2N	27.4±0.47 cd	178±5.73 cd	0.06±0.00	281±7.94 d	174±5.71	661±12.1 bcd
M3K	28.1±0.70 cd	194±3.93 de	0.05±0.00a	336±5.42 f	212±6.71 b	770±8.68 f
M3L	24.5±0.62 bc	164±5.55 c	0.07±0.00a	302±14.0 de	214±4.58 b	704±14.5 de
M3N	27.8±1.23 cd	205±7.01 ef	0.07±0.00	320±12.3 ef	199±3.07	753±19.7 ef
CSK	19.3±0.57 a	129±1.76 b	0.06±0.00a	39.5±1.40 a	560±12.9d	748±14.2 ef
CSL	17.7±0.58 a	123±2.96 ab	0.03±0.00a	32.9±1.00 a	512±7.63d	686±10.4 cd
GK	29.0±1.44 d	108±3.66 a	0.03±0.00 a	138±7.21 b	333±8.73c	608±20.5 ab
GL	26.6±1.01 bcd	109±4.48 a	0.03±0.00 a	124±5.78 b	340±8.53c	600±18.0 a
p-value (substrate *plant)	p=0.205	p<0.05	p=0.376	p=0.064	p<0.05	p=0.139

Mineral nitrogen. The data presented in Tables 10 and 11 give information about the mineral nitrogen (NH_4^+-N and NO_3^--N) concentrations. Optimal ammonia concentrations in growth media should be less than 1 mg·kg^{-1} and nitrate concentrations in the range of 100-200 mg·kg^{-1} (Table 4). Only mix 3 had desirable ammonia contcentrations before the experiment, mix 1 had slightly higher, 1.07mg·kg^{-1}. There was no substrate with appropriate nitrate contcentration among the five substrates, mix 1 with peat had more or less acceptable nitrate concentration while the commercial substrate was almost twice above the optimal range. Low nitrate contcentrations may be due to insufficient oxygen supply and a high pH, but the highest pH was in mix 3, while mix 1 and 2 had similar pH values. During the experiment, ammonia and nitrate contcentrations decreased in mix 1, commercial and Grand substrate, but increased in mixes 2 and 3 (wood foam substrates).

Table 10: Ammonia and nitrate (mg·kg^{-1}) concentrations before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	NH_4^+-N	NO_3^--N
Mix1	1.07±0.03 a	87.0±2.81 c
Mix2	1.40±0.05 a	0.60±0.02 a
Mix3	0.48±0.02 a	0.62±0.01 a
Commercial substrate	40.3±1.53 b	395±6.64 d
Grand substrate	2.27±0.09 a	18.8±0.52 b

Table 11: Ammonia and nitrate (mg·kg^{-1}) concentrations at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate, plant for NH_4^+-N and their interaction factors. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	NH_4^+-N	NO_3^--N
M1K	0.60±0.01 ab	69.5±2.37e
M1L	0.50±0.02 a	29.6±0.92e
M1N	0.83±0.01 bc	102±2.33
M2K	3.73±0.09 g	3.08±0.11a
M2L	4.51±0.14 h	4.58±0.14a
M2N	5.09±0.16 i	8.67±0.18
M3K	0.92±0.02 cd	32.4±1.01d
M3L	1.05±0.02 cde	52.1±1.05d
M3N	0.93±0.02 cd	51.2±1.47
CSK	1.60±0.03 f	18.5±0.49c
CSL	1.75±0.04 f	35.3±1.13c
GK	1.19±0.04 de	7.40±0.21b
GL	1.28±0.03 e	6.45±0.13b

Phosphorus and potassium optimal concentrations in growth media should be in the range of 6-9 mg·kg^{-1} and 150-200 mg·kg^{-1} (Table 4), respectively. Tables 12 and 13 show results of CAL extraction of phosphorus and potassium. Generally, P and K concentrations significantly exceeded the optimal ranges and concentrations of these macronutrients decreased after plant growth. The lowest concentrations of P and K, which mean more suitable concentrations for growth media, were found in the commercial substrate, whereas the Grand substrate had slightly higher values. The highest concentrations of P and K were found in mixes 3 and 1 compared to mix 2.

Table 12: Phosphorus and potassium concentrations (mg·kg^{-1}) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	P	K
Mix1	729±20.5 d	5680±102 d
Mix2	571±18.4 c	5030±76.5 c
Mix3	724±17.9 d	6500±83.4 e
Commercial substrate	164±4.33 a	1180±42.7 a
Grand substrate	342±7.16 b	2100±55.9 b

Table 13: Phosphorus and potassium concentrations (mg·kg^{-1}) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor; plant*substrate interaction for K. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	P	K
M1K	620±7.44 d	5650±107 d
M1L	627±8.09d	5250±18.0 d
M1N	680±15.1	5770±29.1
M2K	564±19.2c	4700±115 c
M2L	564±13.9c	4790±39.5 c
M2N	551±7.88	5110±135
M3K	704±20.2e	5700±159e
M3L	716±20.9e	5980±93.6e
M3N	689±18.1	6410±169
CSK	161±2.72a	615±4.06 a
CSL	162±2.12a	607±19.7 a
GK	318±4.20b	1940±34.8 b
GL	325±6.50b	1940±56.8 b
p-value (plant*substrate)	p=0.990	p<0.05

Micronutrients: manganese, iron, copper and zinc after EDTA extraction. Plant available concentrations of the micronutrients Mn, Fe, Cu and Zn are given in the Tables 14 and 15. Optimal ranges in substrate for Mn and Fe are 0.3-3 mg·kg^{-1}, for Cu is 70-500 mg·kg^{-1} while for Zn is 200-1800 mg·kg^{-1} (Table 4). Before the experiment, concentrations of manganese and iron were several times higher than the optimal range. Conversely, concentrations of copper and zinc were lower than the desirable range in all substrates. Post hoc analyses reveal that mix 2 had the lowest concentrations of the considered micronutrients.

Table 14: Manganese, iron, copper and zinc concentrations (mg·kg^{-1}) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Mn	Fe	Cu	Zn
Mix1	328±6.22b	1450±28.6 d	7.92±0.17 b	22.1±0.68 a
Mix2	271±5.04 a	732±12.6 a	6.34±0.20 a	20.3±0.52 a
Mix3	310±5.11 b	867±11.9 b	7.25±0.23 b	22.9±0.84 a
Commercial s.	379±6.31 c	2120±38.7 e	18.5±0.30 c	63.7±1.61 c
Grand substrate	424±7.57 d	1010±33.6 c	7.15±0.16 b	29.6±0.87 b

Table 15: Manganese, iron, copper and zinc concentrations (mg·kg^{-1}) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor; plant factor for Mn; plant*substrate interaction for Mn and Fe. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Mn	Fe	Cu	Zn
M1K	300±5.82b	1544±32.1b	8.69±0.20a	23.1±0.61b
M1L	300±4.48 b	1340±15.8b	7.92±0.05a	23.3±0.67b
M1N	298±9.03 b	1520±27.7	9.43±0.28	23.5±0.38
M2K	240±4.12 a	1176±17.9a	5.91±0.17a	17.9±0.41a
M2L	252±7.74 a	1192±36.0a	6.29±0.21a	19.1±0.43a
M2N	268±6.58 a	1236±36.5	7.59±0.17	19.9±0.52
M3K	303±2.22 b	1415±33.0b	8.41±0.28a	23.7±0.74b
M3L	316±6.45 b	1501±32.8b	7.76±0.17a	23.2±0.76b
M3N	304±8.53 b	1232±24.8	9.27±0.28	23.7±0.36
CSK	452±6.04 d	2013±37.2d	17.2±0.29b	68.5±1.33d
CSL	442±7.93 d	1982±33.0d	18.3±0.22b	68.1±2.25d
GK	379±8.58 c	992±6.35c	7.20±0.18a	26.9±0.62c
GL	456±10.0 d	1093±31.8c	7.73±0.26a	31.8±0.46c
p-value (plant*substrate)	p<0.05	p<0.05	p=0.249	p=0.060

Heavy metals extracted with ammonium nitrate. Results of ammonium nitrate extraction of heavy metals are shown in the Table 16 and 17. As compost standards are based on total concentrations, we cannot compare these data. However, the concentrations after extraction were very small and expressed in $\mu g \cdot kg^{-1}$. Mix 1 with peat had the highest pollutants concentrations before the experiment compared to mixes 2 and 3, commercial and Grand substrates, whereas, the latter had the lowest concentrations of heavy metals with the exception of Cu, Zn and Cd. Mix 2 with larger amount of wood foam in the substrate formulation had higher extractable metal concentrations compared to mix 3, which contained lower amounts of wood foam, before and after the experiment, except for Cu and Zn. There is a clear trend of decreasing heavy metals concentrations only in mix 1 after the experiment, while other substrates, generally, had both increasing and decreasing trends depending on the element.

Table 16: Available heavy metals concentrations ($\mu g \cdot kg^{-1}$) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Cr	Ni	Co	Cu	Zn	As	Cd	Pb
Mix1	201±6.20 c	128±3.95 d	84.5±2.56 d	442±13.2 c	488±14.6 c	263±8.34 d	0.74±0.02 d	20.5±0.68 d
Mix2	75.9±2.37b	85.6±2.43 c	48.0±1.28 c	228±7.36 b	196±6.10 a	220±6.92 c	0.48±0.01 c	18.1±0.61 c
Mix3	6.18±0.21 a	39.7±1.27 b	10.9±0.32 b	35.3±0.84 a	312±10.3 b	40.2±1.38 b	0.16±0.00 a	4.38±0.12 b
Commercial	5.35±0.18 a	39.0±1.21 b	5.78±0.15 a	34.3±0.91 a	358±9.37 b	47.0±1.44 b	0.14±0.00 a	3.28±0.11 b
Grand	2.35±0.07 a	13.4±0.39 a	4.15±0.12 a	48.8±1.65 a	910±25.6 d	1.99±0.06 a	0.36±0.02 b	0.47±0.01 a

Table 17: Available heavy metals concentrations ($\mu g \cdot kg^{-1}$) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor; plant factor for Cr, Ni, Zn; plant*substrate interaction for Cr, Ni, Cu, Cd. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Cr	Ni	Co	Cu	Zn	As	Cd	Pb
M1K	26.7±0.57 bc	54.3±0.78 abc	22.6±0.08b	99.8±0.87c	142±3.34 ab	124±2.26b	0.20±0.01c	5.70±0.13b
M1L	34.0±0.64 bc	64.3±1.93 abcd	26.2±0.96b	114±4.85c	136±2.20 ab	110±4.53b	0.26±0.01c	4.49±0.24b
M1N	28.0±0.33 bc	63.1±1.91 abcd	27.1±0.80	97.2±1.31	109±1.80 ab	227±6.10	0.22±0.01	5.20±0.22
M2K	40.2±1.30 cd	122±1.98 e	46.2±2.05d	95.0±1.51c	57.9±0.46 a	358±6.19d	0.16±0.00b	17.9±0.66d
M2L	31.5±1.06 bc	78.6±0.73 cd	42.3±1.12d	129±4.45c	66.6±1.83 ab	376±10.4d	0.18±0.01b	15.3±0.23d
M2N	42.0±0.69 d	100±2.09 e	46.0±1.29	262±3.94	67.2±1.55 ab	399±17.5	0.33±0.00	19.4±0.67
M3K	31.7±0.93 bc	87.1±1.72 d	37.3±0.62c	165±1.39d	87.1±1.83 ab	334±7.11c	0.31±0.02d	14.5±0.25c
M3L	25.6±0.86 bc	68.1±1.69 bcd	30.1±0.57c	112±2.80d	54.3±0.76 a	292±9.16c	0.27±0.01d	14.7±0.15c
M3N	33.6±1.00 b	85.5±0.88 cd	37.8±0.42	159±8.37	168±1.97 b	353±5.13	0.28±0.00	14.3±0.60
CSK	8.11±0.35 a	46.6±2.39 abcd	11.0±0.61a	48.7±1.30b	291±10.1 d	30.9±0.66 a	0.18±0.01b	2.80±0.11ab
CSL	6.87±0.19 a	43.1±1.92 ab	11.1±0.66a	54.9±1.51b	257±4.51 c	29.0±0.94 a	0.17±0.00b	2.88±0.13ab
GK	7.75±0.28 a	40.8±1.12 ab	7.26±0.23a	42.7±1.33 a	278±9.47 cd	52.8±1.88 a	0.12±0.01a	0.56±0.01a
GL	9.47±0.31 a	35.7±0.63 a	5.81±0.13a	41.4±1.61 a	264±10.1 c	35.9±0.92 a	0.11±0.00a	0.58±0.04a
p-value (plant*substrate)	p<0.05	p<0.05	p<0.05	p<0.05	p=0.241	p<0.05	p<0.05	p=0.054

Total element concentrations in substrates. Table 18 and 19 show the total concentrations of macronutrients and micronutrients in the substrates. In general, concentrations of the nutrients Mg, P, K, Ca, Mn dropped after growth experiment in all substrates, except of mix 2. In mix 2, there is a trend that concentrations of P, K, Ca, Mn raised after plant growth. The highest concentrations of the nutrients were found in mix 1 with peat and the lowest ones in the Grand substrate.

Table 18: Total nutrient concentrations ($g \cdot kg^{-1}$) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Mg	P	K	Ca	Mn
Mix1	48.2±1.15 d	1.36±0.05 d	25.9±0.88 c	86.6±2.38 c	0.90±0.03 b
Mix2	42.2±1.23 c	0.88±0.03 b	20.4±0.66 b	54.6±1.79 a	0.66±0.02 a
Mix3	44.5±1.28 cd	1.17±0.03 c	28.0±0.94 c	75.0±2.40 b	0.86±0.01 b
Commercial	21.1±0.72 a	0.45±0.01 a	11.2±0.33 a	54.4±1.90 a	0.88±0.03 b
Grand	34.6±1.03 b	0.91±0.03 b	12.9±0.40 a	72.9±2.26 b	1.28±0.03 c

Table 19: Total nutrient concentrations ($g \cdot kg^{-1}$) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor; plant*substrate interaction for Ca. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Mg	P	K	Ca	Mn
M1K	50.6±1.54e	1.01±0.05c	23.5±0.86d	64.8±0.77c	0.85±0.01c
M1L	48.5±0.61e	1.05±0.04c	22.9±0.37d	67.9±1.84c	0.89±0.02c
M1N	41.9±1.11	0.93±0.02	22.7±1.36	66.0±1.35	0.84±0.04
M2K	37.7±2.16c	0.91±0.03b	20.5±1.14c	61.3±2.78b	0.72±0.01a
M2L	37.6±0.74c	0.91±0.03b	18.3±0.40c	55.8±1.15b	0.70±0.00a
M2N	39.6±2.54	0.94±0.04	22.0±1.19	59.3±3.45	0.77±0.02
M3K	39.5±1.93d	1.01±0.03c	23.3±0.39d	71.5±1.13d	0.78±0.01b
M3L	42.7±2.26d	1.15±0.03c	24.5±0.73d	73.3±2.05d	0.86±0.02b
M3N	42.4±1.09	1.07±0.02	23.9±0.89	69.7±0.84	0.82±0.02
CSK	19.3±0.47a	0.39±0.00a	10.3±0.16a	46.4±1.94a	0.93±0.03d
CSL	20.5±0.49a	0.39±0.00a	10.1±0.30a	55.0±1.12a	0.91±0.02d
GK	33.3±0.29b	0.94±0.02b	12.8±0.23b	74.0±0.32d	1.25±0.02e
GL	34.0±1.11b	0.87±0.01b	11.9±0.10b	73.4±1.38d	1.25±0.02e
p-value (plant* substrate)	p=0.398	p<0.05	p=0.075	p<0.05	p<0.05

Also, it is clear that in wood foam comprising substrates, mix 3 had higher concentrations of macronutrients, micronutrients and heavy metals (Tables 20, 21) compared to mix 2. However, if to compare with Austrian metal standards for compost, there is no substrate among the analyzed in the present work where pollutants exceed critical values.

Table 20: Total heavy metals concentrations (mg·kg^{-1}) before the experiment. Values are means ± s.e. (n=4). One-way ANOVA revealed significance (p=0.000) of the substrate factor. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Cr	Ni	Cu	Zn	Cd	Pb
Mix1	44.3±1.29 b	35.5±1.16 b	36.4±1.13 a	105±2.57 b	0.33±0.00 b	16.4±0.52 b
Mix2	31.4±1.15 a	26.4±0.51 a	33.8±1.02 a	79.1±1.82 a	0.28±0.01 a	12.7±0.27 a
Mix3	45.0±1.22 b	34.7±0.67 b	34.3±0.96 a	106±1.99 b	0.34±0.01 b	15.8±0.49 b
Commercial	76.8±2.52 c	42.5±0.85 c	62.8±1.87 b	165±3.96 c	0.49±0.00 d	27.8±1.13 c
Grand	43.5±1.23 b	71.7±2.14 d	33.2±0.67 a	109±0.87 b	0.44±0.01 c	12.9±0.34 a

Table 21: Total heavy metals concentrations (mg·kg^{-1}) at time of harvesting. Values are means ± s.e. (n=4). Two-way ANOVA revealed significance (p<0.05) of the substrate factor; plant factor for Cu. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

Substrate	Cr	Ni	Cu	Zn	Cd	Pb
M1K	82.9±6.32c	34.5±1.22b	41.7±1.49 bcd	104±0.76b	0.37±0.00b	17.7±0.45c
M1L	45.3±2.93c	34.9±0.80b	43.2±2.31 cd	107±3.00 b	0.36±0.00b	17.5±0.29c
M1N	40.2±0.48	32.7±0.24	37.2±1.18 abc	103±1.87	0.35±0.00	17.2±0.18
M2K	34.9±1.20a	29.8±0.77a	33.6±1.00 a	96.0±4.17a	0.33±0.01a	15.4±0.26b
M2L	35.6±1.76 a	29.5±0.71a	37.0±0.95 abc	93.3±1.24a	0.34±0.01a	16.1±0.85b
M2N	38.4±0.60	31.1±1.74	35.7±0.93 ab	96.9±3.97	0.36±0.01	15.1±0.59
M3K	39.6±1.63ab	30.7±0.56ab	34.6±0.44 a	104±2.54b	0.36±0.01b	16.1±0.46bc
M3L	40.3±1.33ab	34.0±0.59ab	38.1±0.81 abc	108±1.88b	0.37±0.01 b	17.5±0.75bc
M3N	39.8±1.70	33.1±0.54	35.7±0.45 ab	103±2.14	0.36±0.01	16.3±0.54
CSK	77.6±4.31d	39.0±1.30c	47.3±0.79 de	174±3.80c	0.52±0.01d	30.1±1.14d
CSL	73.5±3.97d	40.4±0.81c	50.5±3.43 e	177±4.10c	0.50±0.01d	30.4±0.47d
GK	46.9±1.55bc	70.7±2.21d	33.6±0.44 a	109±1.73b	0.44±0.00c	13.0±0.18a
GL	49.5±1.49bc	71.4±2.99d	32.9±0.11 a	108±0.71b	0.45±0.01c	13.0±0.13a
p-value (plant* substrate)	p<0.05	p=0.764	p=0.562	p=0.658	p=0.412	p=0.604

Total element concentrations in plant tissue. Total concentrations of nutrients and pollutants in roots and shoots are given in the Table 22 and 23, respectively. Optimal and critical ranges of total element concentrations in plant tissue are represented in the Table 23. Generally, the nutrients concentrations of Mg, P, K, Ca were within or above the optimal ranges in plant shoots. The only slight indication of deficiency of Ca was found in mix 2 and 3 with ryegrass, 1.73 $g \cdot kg^{-1}$ and 1.98 $g \cdot kg^{-1}$, respectively, whereas the optimal range is 2.0-9.4 $g \cdot kg^{-1}$. It was observed that the total concentrations of chromium, manganese, nickel, copper, and zinc in shoots of all treatments were within the optimal values. The total concentrations of cadmium and lead were below critical levels of plant toxicity (Table 23).

While the total nutrient concentrations were very similar in both mixes 2 and 3 in roots of both plant species, the total nutrients concentrations of Nasturtium shoots were lower in mix 3, compared to the concentrations in shoots of mix 2.

Table 22: Total element concentrations in roots (mg·kg^{-1}). Values are means ± s.e. (n=4). Two-way ANOVA revealed significance ($p<0.05$) of the substrate factor for Cr, Ni, Zn, Cd; plant factor for K, Ni, Zn, Cd; plant*substrate interaction for Ni and Cd. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

	Mg (g·kg^{-1})	P (g·kg^{-1})	K (g·kg^{-1})	Ca (g·kg^{-1})	Cr	Mn	Ni	Cu	Zn	Cd	Pb
M1K	4.53±0.13	3.46±0.11	46.4±2.08	7.15±0.16	4.72±0.07a	39.0±2.84	4.33±0.08 a	28.7±0.86	54.7±2.97 a	0.34±0.03 b	3.72±0.23
M1L	3.46±0.08	3.48±0.10	36.3±1.03	7.09±0.23	4.01±0.05a	28.3±1.23	6.25±0.17 ab	29.3±0.67	79.0±4.08 a	0.15±0.01 a	4.23±0.25
M2K (n=3)	8.24±0.15	3.92±0.16	89.3±1.55	4.89±0.20	3.58±0.14a	327±35.3	4.06±0.43 a	27.1±2.38	34.1±1.55 a	0.08±0.00 a	4.48±0.13
M2L	8.17±0.32	3.68±0.14	44.2±2.28	11.1±0.72	3.83±0.20a	217±16.4	6.60±0.55 a	29.3±1.97	55.2±4.26 a	0.09±0.01 a	5.94±0.23
M3K (n=3)	6.89±0.51	4.76±0.39	82.6±6.89	5.73±1.40	3.25±0.38a	144±10.9	4.13±0.13 a	25.5±2.01	46.9±2.42 a	0.18±0.02 a	4.85±0.22
M3L	7.41±0.27	3.37±0.13	52.5±3.00	12.2±0.66	3.50±0.16a	151±4.88	4.56±0.30 a	29.2±2.24	59.0±2.27 a	0.10±0.00 a	4.57±0.24
CSK (n=3)	5.47±0.22	2.90±0.06	35.3±1.35	8.31±0.47	12.1±0.74b	95.3±2.26	9.95±0.39 b	45.8±0.71	74.2±6.29 a	0.90±0.14 d	6.35±0.24
CSL	2.70±0.11	2.49±0.07	15.6±0.25	8.83±0.66	7.60±0.36b	179±14.8	7.38±0.51 ab	31.2±0.89	167±32.0 b	0.43±0.02 b	6.29±0.45
GK	5.67±0.17	4.03±0.09	50.9±2.12	6.99±0.41	13.7±0.93c	108±8.31	11.2±0.59 b	31.9±1.37	56.9±4.14 a	0.71±0.05 c	2.93±0.11
GL	5.15±0.08	3.16±0.07	18.3±0.30	10.6±0.32	23.9±1.71c	238±14.9	32.9±2.43 c	247±19.8	184±11.1 b	0.64±0.02 c	3.52±0.17
p-value (plant* substrate)	p=0.221	p=0.473	p=0.371	p=0.186	p=0.892	p=0.219	p<0.05	p=0.055	p<0.05	p<0.05	p=0.338

Table 23: Total element concentrations in shoots ($mg \cdot kg^{-1}$). Values are means ± s.e. (n=4). Two-way ANOVA revealed significance ($p<0.05$) of the substrate factor for K, Mn, Zn, Cd; plant factor for P, Cr, Cu, Zn; plant*substrate interaction for Cr, Mn, Zn. Means with the same letter within a column are not significantly different according to Tukey's-b test (α=0.05).

	Mg($g \cdot kg^{-1}$)	P($g \cdot kg^{-1}$)	K($g \cdot kg^{-1}$)	Ca($g \cdot kg^{-1}$)	Cr	Mn	Ni	Cu	Zn	Cd	Pb
M1K	5.69±0.11	4.58±0.27	91.4±4.79b	10.6±0.40	2.42±0.11	55.3±2.77a	1.40±0.09	9.88±0.19	63.5±1.66 e	0.08±0.00c	0.48±0.06
M1L	4.59±0.17	2.79±0.09	87.9±3.21b	4.52±0.08	2.15±0.07	43.5±2.05a	1.28±0.11	10.1±0.50	43.3±1.32 cd	0.05±0.00c	0.81±0.09
M2K (n=3)	5.46±0.26	5.93±0.19	95.0±2.79b	6.55±0.25	0.96±0.03	48.0±1.97a	0.53±0.05	5.58±0.17	36.8±1.51 bc	0.06±0.00b	0.17±0.01
M2L	4.37±0.32	2.03±0.15	87.3±6.13b	1.73±0.06	2.56±0.13	47.2±1.26a	1.15±0.11	6.17±0.28	24.6±0.77 ab	0.03±0.00b	0.43±0.02
M3K (n=3)	4.44±0.20	3.62±0.15	89.9±3.56b	3.01±0.08	1.43±0.08	40.8±0.27a	0.66±0.04	6.39±0.52	21.7±0.39 a	0.04±0.00a	0.11±0.01
M3L	3.28±0.14	2.46±0.10	104±2.67b	1.98±0.07	3.51±0.20	52.5±1.07a	1.99±0.13	6.41±0.38	26.0±1.92 ab	0.02±0.00a	0.17±0.01
CSK (n=3)	4.46±0.21	2.29±0.09	53.5±2.81a	19.6±0.67	1.86±0.12	46.0±1.61a	0.69±0.03	7.44±0.22	134±4.30 g	0.22±0.02e	0.16±0.01
CSL	5.33±0.14	2.70±0.05	65.7±1.35a	11.9±0.35	2.39±0.19	35.6±1.65a	1.22±0.07	11.1±0.40	55.5±1.16 de	0.12±0.00e	0.18±0.01
GK	2.97±0.10	3.56±0.08	42.7±0.48a	9.36±0.65	1.87±0.08	72.8±2.70b	0.52±0.02	4.31±0.21	86.9±3.34 f	0.10±0.01d	0.12±0.00
GL	2.84±0.03	5.40±0.09	77.8±1.01a	4.96±0.15	2.26±0.11	55.2±2.67b	0.91±0.06	8.52±0.34	48.5±3.62 cd	0.07±0.01d	0.13±0.00
Normal range	1.0-2.1(1)	1.2-5.0(1)	14-64(1)	2.0-9.4(1)	0.02-14(2)	15-150(2)	0.1-5(2)	3-20(2)	15-150(2)	0.1-1(2)	2-5(2)
p-value (plant* substrate)	p=0.215	p<0.05	p=0.200	p=0.205	p<0.05	p<0.05	p=0.235	p=0.076	p<0.05	p=0.152	p=0.281

(1) Silber and Bartal (2008); (2) Adriano (2001).

4. Conclusions

The experimental results showed that wood foam is not suitable for peat substitution in the form it was used.

Wood foam has acceptable pH and EC and a good physical property such as a high water holding capacity. WHC of mix 2 was even higher than in the mix with peat and in the commercial substrate, also the bulk density of mix 2 was lower than in the one with peat before the experiment, which characterizes that as a positive property. However, the experiment demonstrated that WHC and bulk density were not water-stable during the plant growth due to compaction. At the same time, fungal growth was observed on the substrate surface where the wood foam ratio was the greatest. Therefore, wood foam is not suitable to substitute peat in growth media.

It is known that at alkaline pH only calcium and magnesium are easily available for plants, whereas micronutrients such as iron, manganese, zinc and copper are more accessible at acid pH. In our experiment pH values of all substrates were alkaline, however EDTA-extractable concentrations of manganese and iron were above optimal range, whereas concentrations of copper and zinc were below that range, but there were no significant differences among substrates after the experiment.

The total cation exchange capacity showed no significant difference after plant growth among all analyzed substrates, but exchangeable Ca was the lowest in mixes 2 and 3 before and after the pot experiment.

Mix 2 and commercial substrate had very similar total Ca concentrations, which were the lowest compared to other media before the pot experiment, but after plant growth Ca concentrations were higher in mix 2 than in the commercial substrates, confirming that CEC of Ca is very low in mixes comprising wood foam compared to other growth media. In response to it, the total nutrient concentrations in plant tissue, indicated deficiency of Ca in ryegrass, grown in wood foam comprising mixes.

Total nitrogen and sulfur contents as well as C/N ratio showed no significant difference among all substrates.

Ammonia concentrations increased after the pot experiment only in mixes containing wood foam, with higher wood foam content resulting in higher ammonia concentration. Nitrate concentrations were below the optimal range in mixes with wood foam before the pot experiment, but increased after plant growth. This might be due to insufficient oxygen supply caused by compaction.

Total metal (Cr, Ni, Cu, Zn, Cd and Pb) concentrations at the beginning were the lowest in mix 2, however all substrates complied with the Austrian metal standards for compost. At the same time, total metal concentrations in plant tissues were within the normal range.

Scope: Wood foam cannot be used directly and the next step might be the evaluating composting process to avoid waste formation.

Annex

A1: Resume of two-way ANOVA applied to dry plant tissue biomass (shoots and roots) results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Dry root weight	,978	4	,244	69,253	,000
	Dry shoot weight	8,311	4	2,078	41,868	,000
Plant	Dry root weight	,575	1	,575	162,771	,000
	Dry shoot weight	,015	1	,015	,310	,582
Substrate * Plant	Dry root weight	,321	4	,080	22,742	,000
	Dry shoot weight	,562	4	,140	2,830	,044

A2: Resume of one-way ANOVA applied to dry cress biomass results after the cress test

Dry cress weight	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,010	4	,003	63,523	,000
Within Groups	,000	10	,000		
Total	,011	14			

A3: Resume of one-way ANOVA applied to bulk density results before the pot experiment

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	,663	12	,055	89,897	,000
Within Groups	,024	39	,001		
Total	,687	51			

A4: Resume of two-way ANOVA applied to WHC results after the pot experiment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	1885,350	4	471,337	1,571E3	,000
Plant	14,400	1	14,400	48,000	,000
Substrate * Plant	78,850	4	19,712	65,708	,000

A5: Resume of one-way ANOVA applied to pH (H_2O, $CaCl_2$) results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
pH (H_2O)	Between Groups	6,369	4	1,592	144,643	,000
	Within Groups	,165	15	,011		
	Total	6,534	19			
pH ($CaCl_2$)	Between Groups	1,216	4	,304	25,583	,000
	Within Groups	,178	15	,012		
	Total	1,394	19			

A6: Resume of two-way ANOVA applied to pH (H_2O, $CaCl_2$) results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	pH (H_2O)	3,986	4	,997	8,492	,000
	pH ($CaCl_2$)	2,358	4	,589	6,238	,001
Plant	pH (H_2O)	,000	1	,000	,002	,963
	pH ($CaCl_2$)	,112	1	,112	1,185	,286
Substrate * Plant	pH (H_2O)	1,857	4	,464	3,956	,012
	pH ($CaCl_2$)	,574	4	,144	1,520	,224

A7: Resume of one-way ANOVA applied to EC results before the pot experiment

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	30,160	4	7,540	218,551	,000
Within Groups	,518	15	,034		
Total	30,678	19			

A8: Resume of two-way ANOVA applied to EC results after the pot experiment

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	42,814	4	10,704	99,657	,000
Plant	1,092	1	1,092	10,170	,003
Substrate * Plant	3,375	4	,844	7,856	,000

A9: Resume of one-way ANOVA applied to total nitrogen, carbon, sulfur content results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
N	Between Groups	1,098	4	,274	137,463	,000
	Within Groups	,030	15	,002		
	Total	1,128	19			
C	Between Groups	385,293	4	96,323	145,467	,000
	Within Groups	9,932	15	,662		
	Total	395,226	19			
S	Between Groups	,039	4	,010	7,055	,002
	Within Groups	,021	15	,001		
	Total	,059	19			
C:N	Between Groups	436,715	4	109,179	181,599	,000
	Within Groups	9,018	15	,601		
	Total	445,733	19			

A10: Resume of two-way ANOVA applied to total nitrogen, carbon, sulfur content results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	N	1,741	4	,435	254,279	,000
	C	158,484	4	39,621	44,076	,000
	S	,260	4	,065	91,397	,000
	C:N	753,628	4	188,407	342,335	,000
Plant	N	,000	1	,000	,166	,686
	C	,225	1	,225	,251	,620
	S	6,011E-9	1	6,011E-9	,000	,998
	C:N	,728	1	,728	1,323	,259
Substrate * Plant	N	,007	4	,002	1,027	,409
	C	10,273	4	2,568	2,857	,041
	S	,004	4	,001	1,352	,274
	C:N	5,939	4	1,485	2,698	,050

A11: Resume of one-way ANOVA applied to CEC results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
Na	Between Groups	533,599	4	133,400	514,226	,000
	Within Groups	3,891	15	,259		
	Total	537,490	19			
Mg	Between Groups	55205,668	4	13801,417	298,995	,000
	Within Groups	692,390	15	46,159		
	Total	55898,058	19			
Al	Between Groups	,215	4	,054	74,868	,000
	Within Groups	,011	15	,001		
	Total	,226	19			
K	Between Groups	258183,300	4	64545,825	963,994	,000
	Within Groups	1004,350	15	66,957		
	Total	259187,650	19			
Ca	Between Groups	351186,300	4	87796,575	383,112	,000
	Within Groups	3437,500	15	229,167		
	Total	354623,800	19			
Total	Between Groups	303831,800	4	75957,950	161,779	,000
	Within Groups	7042,750	15	469,517		
	Total	310874,550	19			

A12: Resume of two-way ANOVA applied to CEC results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Na^{+}	472,227	4	118,057	47,262	,000
	Mg^{2+}	79758,921	4	19939,730	303,272	,000
	Al^{3+}	,094	4	,023	59,131	,000
	K^{+}	496429,717	4	124107,429	735,681	,000
	Ca^{2+}	604803,939	4	151200,985	662,668	,000
	Total	444534,869	4	111133,717	171,750	,000
Plant	Na^{+}	54,192	1	54,192	21,695	,000
	Mg^{2+}	3442,509	1	3442,509	52,359	,000
	Al^{3+}	,025	1	,025	62,173	,000
	K^{+}	5516,618	1	5516,618	32,701	,000
	Ca^{2+}	590,954	1	590,954	2,590	,118
	Total	27150,739	1	27150,739	41,960	,000
Substrate * Plant	Na^{+}	15,807	4	3,952	1,582	,205
	Mg^{2+}	1814,766	4	453,691	6,900	,000
	Al^{3+}	,044	4	,011	27,563	,000
	K^{+}	1686,129	4	421,532	2,499	,064
	Ca^{2+}	6104,723	4	1526,181	6,689	,001
	Total	4872,696	4	1218,174	1,883	,139

A13: Resume of one-way ANOVA applied to nitrogen mineral results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
NH_4-N	Between Groups	4865,090	4	1216,272	645,498	,000
	Within Groups	28,264	15	1,884		
	Total	4893,353	19			
NO_3-N	Between Groups	453688,754	4	113422,189	2,709E3	,000
	Within Groups	628,074	15	41,872		
	Total	454316,828	19			

A14: Resume of two-way ANOVA applied to nitrogen mineral results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	NH_4-N	63,297	4	15,824	1,167E3	,000
	NO_3-N	13397,976	4	3349,494	823,129	,000
Plant	NH_4-N	,433	1	,433	31,961	,000
	NO_3-N	3,130	1	3,130	,769	,387
Substrate * Plant	NH_4-N	,912	4	,228	16,806	,000
	NO_3-N	4541,001	4	1135,250	278,985	,000

A15: Resume of one-way ANOVA applied to phosphorus and potassium concentrations results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
P	Between Groups	980520,500	4	245130,125	266,920	,000
	Within Groups	13775,500	15	918,367		
	Total	994296,000	19			
K	Between Groups	8,549E7	4	2,137E7	951,667	,000
	Within Groups	336875,000	15	22458,333		
	Total	8,583E7	19			

A16: Resume of two-way ANOVA applied to phosphorus and potassium concentrations results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	P	1655609,198	4	413902,300	595,514	,000
	K	1,708E8	4	4,269E7	1,628E3	,000
Plant	P	303,966	1	303,966	,437	,513
	K	950,482	1	950,482	,036	,850
Substrate * Plant	P	200,000	4	50,000	,072	,990
	K	489995,281	4	122498,820	4,670	,005

A17: Resume of one-way ANOVA applied to manganese, iron, copper and zinc concentrations results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
Mn	Between Groups	57784,300	4	14446,075	99,754	,000
	Within Groups	2172,250	15	144,817		
	Total	59956,550	19			
Fe	Between Groups	5100939,700	4	1275234,925	416,603	,000
	Within Groups	45915,500	15	3061,033		
	Total	5146855,200	19			
Cu	Between Groups	412,586	4	103,147	539,380	,000
	Within Groups	2,868	15	,191		
	Total	415,455	19			
Zn	Between Groups	5303,712	4	1325,928	351,162	,000
	Within Groups	56,638	15	3,776		
	Total	5360,350	19			

A18: Resume of two-way ANOVA applied to manganese, iron, copper and zinc concentrations results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Mn	230536,613	4	57634,153	319,763	,000
	Fe	4269311,520	4	1067327,880	310,709	,000
	Cu	1225,606	4	306,402	16,162	,000
	Zn	13244,972	4	3311,243	849,938	,000
Plant	Mn	3337,381	1	3337,381	18,516	,000
	Fe	416,219	1	416,219	,121	,730
	Cu	22,410	1	22,410	1,182	,286
	Zn	12,555	1	12,555	3,223	,083
Substrate * Plant	Mn	9056,826	4	2264,207	12,562	,000
	Fe	119986,144	4	29996,536	8,732	,000
	Cu	108,379	4	27,095	1,429	,249
	Zn	39,724	4	9,931	2,549	,060

A19: Resume of one-way ANOVA applied to available heavy metals concentrations results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
Cr	Between Groups	117293,941	4	29323,485	862,518	,000
	Within Groups	509,963	15	33,998		
	Total	117803,904	19			
Ni	Between Groups	33199,840	4	8299,960	437,869	,000
	Within Groups	284,330	15	18,955		
	Total	33484,170	19			
Co	Between Groups	19646,209	4	4911,552	756,665	,000
	Within Groups	97,366	15	6,491		
	Total	19743,575	19			
Cu	Between Groups	512011,333	4	128002,833	679,819	,000
	Within Groups	2824,345	15	188,290		
	Total	514835,678	19			
Zn	Between Groups	1216790,300	4	304197,575	362,212	,000
	Within Groups	12597,500	15	839,833		
	Total	1229387,800	19			
As	Between Groups	224495,079	4	56123,770	609,459	,000
	Within Groups	1381,318	15	92,088		
	Total	225876,397	19			
Cd	Between Groups	,982	4	,246	408,062	,000
	Within Groups	,009	15	,001		
	Total	,991	19			
Pb	Between Groups	1363,448	4	340,862	485,999	,000
	Within Groups	10,520	15	,701		
	Total	1373,968	19			

A20: Resume of two-way ANOVA applied to available heavy metals concentrations results after the pot experiment

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Cr	5499,998	4	1374,999	208,998	,000
	Ni	18577,606	4	4644,401	51,141	,000
	Co	6734,218	4	1683,554	123,049	,000
	Cu	52737,919	4	13184,480	285,911	,000
	Zn	444947,539	4	111236,885	45,924	,000
	As	752730,354	4	188182,588	621,472	,000
	Cd	,149	4	,037	84,537	,000
	Pb	1886,076	4	471,519	72,135	,000
Plant	Cr	41,698	1	41,698	6,338	,017
	Ni	2268,638	1	2268,638	24,981	,000
	Co	36,730	1	36,730	2,685	,112
	Cu	20,306	1	20,306	,440	,512
	Zn	14175,602	1	14175,602	5,852	,022
	As	831,015	1	831,015	2,744	,108
	Cd	9,000E-5	1	9,000E-5	,205	,654
	Pb	18,010	1	18,010	2,755	,107
Substrate * Plant	Cr	355,465	4	88,866	13,508	,000
	Ni	3130,788	4	782,697	8,618	,000
	Co	184,627	4	46,157	3,374	,022
	Cu	8355,238	4	2088,810	45,297	,000
	Zn	14076,002	4	3519,001	1,453	,241
	As	3995,801	4	998,950	3,299	,024
	Cd	,014	4	,004	8,003	,000
	Pb	68,572	4	17,143	2,623	,054

A21: Resume of one-way ANOVA applied to total nutrient concentrations results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
Mg	Between Groups	1843,145	4	460,786	95,092	,000
	Within Groups	72,685	15	4,846		
	Total	1915,830	19			
P	Between Groups	1,921	4	,480	118,612	,000
	Within Groups	,061	15	,004		
	Total	1,981	19			
K	Between Groups	905,927	4	226,482	119,358	,000
	Within Groups	28,462	15	1,897		
	Total	934,389	19			
Ca	Between Groups	3124,137	4	781,034	41,839	,000
	Within Groups	280,012	15	18,667		
	Total	3404,150	19			
Mn	Between Groups	,828	4	,207	84,505	,000
	Within Groups	,037	15	,002		
	Total	,865	19			

A22: Resume of one-way ANOVA applied to total heavy metals concentrations results before the pot experiment

		Sum of Squares	df	Mean Square	F	Sig.
Cr	Between Groups	4577,893	4	1144,473	115,320	,000
	Within Groups	148,865	15	9,924		
	Total	4726,758	19			
Ni	Between Groups	4870,963	4	1217,741	206,999	,000
	Within Groups	88,242	15	5,883		
	Total	4959,205	19			
Cu	Between Groups	2590,720	4	647,680	112,654	,000
	Within Groups	86,239	15	5,749		
	Total	2676,959	19			
Zn	Between Groups	16175,266	4	4043,817	166,811	,000
	Within Groups	363,629	15	24,242		
	Total	16538,895	19			
Cd	Between Groups	,118	4	,029	139,940	,000
	Within Groups	,003	15	,000		
	Total	,121	19			
Pb	Between Groups	619,965	4	154,991	97,786	,000
	Within Groups	23,775	15	1,585		
	Total	643,740	19			

A23: Resume of two-way ANOVA applied to total element concentrationsin substrates results after the pot experiment

Source	Dependent Var	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Mg	3810,994	4	952,748	129,306	,000
	P	2,473	4	,618	199,626	,000
	K	1253,898	4	313,474	246,612	,000
	Ca	3005,852	4	751,463	79,262	,000
	Mn	1,312	4	,328	384,614	,000
	Cr	8304,249	4	2076,062	27,454	,000
	Ni	9170,418	4	2292,604	298,263	,000
	Cu	1307,055	4	326,764	36,165	,000
	Zn	33778,309	4	8444,577	318,723	,000
	Cd	,165	4	,041	281,233	,000
	Pb	1433,629	4	358,407	322,486	,000
Plant	Mg	3,283	1	3,283	,446	,510
	P	,004	1	,004	1,357	,253
	K	2,981	1	2,981	2,345	,136
	Ca	22,892	1	22,892	2,415	,131
	Mn	,003	1	,003	3,194	,084
	Cr	282,067	1	282,067	3,730	,063
	Ni	12,056	1	12,056	1,568	,220
	Cu	48,312	1	48,312	5,347	,028
	Zn	15,191	1	15,191	,573	,455
	Cd	,000	1	,000	,000	1,000
	Pb	1,884	1	1,884	1,695	,203
Substrate * Plant	Mg	30,926	4	7,732	1,049	,398
	P	,046	4	,012	3,744	,014
	K	12,032	4	3,008	2,366	,075
	Ca	214,947	4	53,737	5,668	,002
	Mn	,014	4	,003	3,978	,010
	Cr	1176,644	4	294,161	3,890	,012
	Ni	14,174	4	3,543	,461	,764
	Cu	27,354	4	6,838	,757	,562
	Zn	64,696	4	16,174	,610	,658
	Cd	,001	4	,000	1,023	,412
	Pb	3,070	4	,768	,691	,604

A24: Resume of two-way ANOVA applied to total element concentrations in roots results after the pot experiment

Source	Dependent Var	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Mg	392,412	4	98,103	1,780	,159
	P	7,129	4	1,782	1,092	,378
	K	3152,953	4	788,238	1,933	,131
	Ca	1862,922	4	465,730	1,950	,128
	Cr	880,873	4	220,218	6,856	,000
	Mn	75775,622	4	18943,906	2,796	,044
	Ni	4976,022	4	1244,005	12,618	,000
	Cu	35234,578	4	8808,645	3,107	,030
	Zn	46696,334	4	11674,083	11,777	,000
	Cd	2,597	4	,649	117,976	,000
	Pb	48,880	4	12,220	1,648	,188
Plant	Mg	35,714	1	35,714	,648	,427
	P	3,031	1	3,031	1,857	,183
	K	4188,789	1	4188,789	10,272	,003
	Ca	669,421	1	669,421	2,803	,104
	Cr	5,278	1	5,278	,164	,688
	Mn	1638,675	1	1638,675	,242	,626
	Ni	620,891	1	620,891	6,298	,018
	Cu	5267,414	1	5267,414	1,858	,183
	Zn	22644,716	1	22644,716	22,844	,000
	Cd	,269	1	,269	48,815	,000
	Pb	15,517	1	15,517	2,093	,158
Substrate * Plant	Mg	335,523	4	83,881	1,522	,221
	P	5,910	4	1,478	,905	,473
	K	1807,223	4	451,806	1,108	,371
	Ca	1581,581	4	395,395	1,656	,186
	Cr	35,277	4	8,819	,275	,892
	Mn	41457,490	4	10364,373	1,530	,219
	Ni	2770,475	4	692,619	7,025	,000
	Cu	29697,382	4	7424,346	2,619	,055
	Zn	13886,586	4	3471,647	3,502	,018
	Cd	,238	4	,060	10,815	,000
	Pb	35,067	4	8,767	1,183	,338

A25: Resume of two-way ANOVA applied to total element concentrations in shoots results after the pot experiment

Source	Dependent Var	Type III Sum of Squares	df	Mean Square	F	Sig.
Substrate	Mg	220,984	4	55,246	,938	,455
	P	14,351	4	3,588	2,368	,075
	K	13580,859	4	3395,215	7,309	,000
	Ca	2368,510	4	592,128	2,141	,100
	Cr	1,666	4	,416	2,646	,053
	Mn	2939,545	4	734,886	13,605	,000
	Ni	1691,056	4	422,764	1,421	,251
	Cu	236,257	4	59,064	1,672	,183
	Zn	29548,259	4	7387,065	31,579	,000
	Cd	,143	4	,036	4,321	,007
	Pb	48,863	4	12,216	1,280	,300
Plant	Mg	59,339	1	59,339	1,008	,323
	P	10,790	1	10,790	7,122	,012
	K	1038,165	1	1038,165	2,235	,145
	Ca	17,695	1	17,695	,064	,802
	Cr	7,280	1	7,280	46,260	,000
	Mn	123,356	1	123,356	2,284	,141
	Ni	430,974	1	430,974	1,448	,238
	Cu	171,504	1	171,504	4,854	,035
	Zn	4789,037	1	4789,037	20,472	,000
	Cd	,000	1	,000	,021	,886
	Pb	17,667	1	17,667	1,851	,184
Substrate * Plant	Mg	363,465	4	90,866	1,543	,215
	P	22,950	4	5,737	3,787	,013
	K	2975,904	4	743,976	1,602	,200
	Ca	1750,908	4	437,727	1,583	,205
	Cr	10,531	4	2,633	16,728	,000
	Mn	2342,928	4	585,732	10,843	,000
	Ni	1753,837	4	438,459	1,474	,235
	Cu	333,951	4	83,488	2,363	,076
	Zn	7822,948	4	1955,737	8,360	,000
	Cd	,060	4	,015	1,812	,152
	Pb	50,851	4	12,713	1,332	,281

Figures

Tables

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