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ALTERNATIVE USE OF WASTE FROM SOILLESS GREENHOUSE CROP PRODUCTION

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Summary

Soilless cultivation of tomatoes in the greenhouse is a source of waste in form of mineral wool and polyethylene. Utilisation of mineral wool waste originating from horticulture is still unresolved and rises a lot of controversy. The aim of the study is to evaluate the possibility of using mineral wool waste in the construction of a green roof. To find the answer, physical properties, i.e. water absorption, water capacity and leachability were assessed for fresh mat and mineral wool waste. Preliminary assessment of pollutants leaching from mineral wool waste was also performed. It was found that the physical properties of the used mats are different from those of the input material. The content of phosphorus in leachate from used mineral wool derived from greenhouse cultivation excludes its use as a material for green roofs construction, if the runoff is discharged into water bodies.

Key words: green roof, mineral wool, physical characteristics, phosphorus.

INTRODUCTION

Greenhouse cultivation area in Poland amounts 17 609 thousand m^2 (GUS 2014). About 20% of this area is occupied by floriculture, similar part by cucumbers and 48% of the area is used for tomatoes cultivation. The most popular type of greenhouse tomatoes cultivation is soilless technology, wherein the substrate consists of mineral wool, polyurethane foam, perlite, expanded clay, coconut fibre, sand or peat (Gorecki *et al.* 2000). In Poland, mineral wool is the most common used substrate. Mineral wools for horticultural crops have density of

65-90 kg m^{-3}. High density results in high water capacity and good water retention. The mineral wool is also characterized by the relevant fiber structure that prevents settling. Some mats have layers with varying density, other are characterised by uniform density throughout the whole volume. Soilless horticulture creates possibility to control the pH, humidity and temperature of the root zone of plants. Mineral wool exhibits superior properties when it comes to protection against pathogenic organisms (Carlile 1995). In some cases, mineral wool with proper physical characteristics could be used twice, but the fitosanitation risk usually makes it a waste after one cultivation period. One hectare of greenhouse cultivation can be the source of 150-200 m^3 of used mineral wool waste (Nowak *et al.* 2013; Knaflewski 2010). Utilisation of mineral wool waste originating from both construction and horticulture is still unresolved and rises a lot of controversy. Only some of companies delivering mineral wool to the market are interested in collection of used mates for the recycling. Some attempts are also made to use this material in land reclamation and recultivation of brownfields (Nowak *et al*. 2013).

The aim of the study was to assess the possibility of usage mineral wool waste from greenhouse tomatoes cultivation in the construction of green roofs. The assessment was made base on physical characteristics of used mats and leaching of phosphorus, as an index of chemical contamination.

Figure 1. Foil wrapped Cultilène® mats used in greenhouse tomato cultivation (waste product).

MATERIAL AND METHODS

Physical characteristics of mineral wool

In this study mineral wool Cultilène® Exact was used (Fig.1). Cultilène® substrates are characterized by high stability and homogeneity. Mineral wool Cultilène® ensures all the parameters required for this type of media (porosity, water absorption, lack of subsidence) are the same as the standard substrate (Report ... 2000).

An important characteristic, from the point of view of plant production, is the water retention and the ability of re-watering after the periodic drying. These characteristics may also be important from the point of view of potential use of mats in a green roof construction. Physical characteristics of the mineral wool were assessed for both fresh and used mates (Fig. 2). Used mats tested in this study originates from the one season greenhouse cultivation of tomatoes.

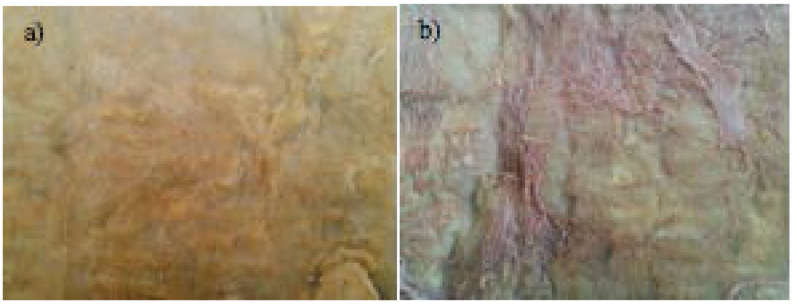


Figure 2. Mineral wool: a) fresh mat, b) used mat with visible roots.

Assessment of physical parameters

Short-term water adsorption was assessed by the method of partial immersion (PN-EN 13162:2002) using the formula:

$$W_p = (m_{24} - m_0)/A_p$$

where:

W_p – water adsorption [kg m^{-2}];
m_0 – initial mass of the sample [kg];
m_{24} – the mass of the sample after partial immersion for 24 hours [kg];
A_p – surface of the bottom of the sample [m^2].

Leachability was assessed by watering of the mineral wool samples for 24 hours. Than samples were placed on sieves and losses of water were assessed for 44 days by controlling the samples weight.

The water sorption curves (pF) were drown to determine the water content available to plants. For the measurement three samples of mineral wool waste and three samples of extensive green roof substrate were used. The pF curves characteristics were measured in the laboratory on undisturbed, standard (100 cm^{-3}) soil samples using reference methods Klute (1986). The moisture content values in the range from 0.4 to 2.0 were determined on a sand table, whereas the amounts of water at the higher pFs were measured in pressure chambers (Zawadzki, 1973). To draw the pF curves, formula given my Mocek *et al*. (1997) was used for calculations. For the needs of analysis available water for plants (AWP) was calculated as difference between moisture contents measured at two matrix potentials pF 1.8 and 3.7 and available water capacity (AWC) was calculated as difference of pF 1.8–4.2.

Testing of mineral wool waste as an element of green roofs construction – small tray experiment.

Mineral wool used in greenhouse tomatoes cultivation was placed in three trays (Fig. 3). In two of trays holes have been shaped in mineral wool and filled with extensive green roof substrate. The substrate was previously tested in column experiment to assess phosphorus leaching and the environmental risk of its use in green roofs construction (Karczmarczyk *et al.* 2012). In the substrate *Lysimachia punctata* (tray 1) and *Jovibarba sobolifera* (tray 2) were planted. Tray 3 (reference) was filled with the mineral wool waste only.

Figure 3. Set up of experiment: a) tray 1: mineral wool waste + extensive green roof substrate + *Lysimachia punctata*; b) tray 2: mineral wool waste + extensive green roof substrate + *Jovibarba sobolifera*; c) tray 3: mineral wool waste (reference site).

The experiment was conducted in the laboratory at room temperature for 51 days. On the first day both trays with plants were saturated by immersion in 8000 ml of water. Subsequently, six rainfall events were simulated with the volumes matched to the rainfalls observed at the meteorological station Warsaw

Ursynów during the summer 2013. Rain simulation was performed using Eijelkamp rainfall simulator. Moisture of both, substrate and mineral wool, were controlled each day by WET-2 probe. The occurrence of the leachate after irrigation and its volume was also noted and used for calculation of water retention and estimation of contaminants loads.

Chemical contamination of used mineral wool

Phosphorus occurrence in green roof runoff adversely affects the receivers. Thus why materials used in green roofs construction should be free of phosphorus (P) or P content should be limited to very low levels. It can be taken as a rule that P content of the construction materials should not exceed 5 mg kg^{-1} (according to the Austrian guidelines for P content in materials for the construction of filters in swimming ponds). In this study phosphorus leaching from used mineral wool was assessed in three independent tests. In the first one, 5 samples of mineral wool (10 g each) were soaked in 500 ml of tap water than pressed and the remaining water was analysed for phosphorus content. The second test was performed in small column with the diameter of 145 mm periodically irrigated with the tap water. The test was performed for 3 months in laboratory conditions. Eight irrigation events were made during this time, with the rate of 9.5-167.4. Collected leachates and the tap water were analysed for P content. The third test was made together with testing of used mineral wool as an element of green roof construction (trays experiment). On the basis of the volume of water, weight of the dry mat and the concentration of $P\text{-}PO_4$ in the effluent P stacked in the mineral wool per unit of dry weight was assessed. Analysis of $P\text{-}PO_4$ in leachates and tap water were made using flow analysis on FIAstar ™ 5000.

RESULTS AND DISCUSSION

Physical properties

The physical properties of the mineral wool have changed as a result of the crop cultivation. Used mineral wool tested in this study is characterized by higher water absorption than the new one. Short-term absorbability amounted 0.58 kg m^{-2} for new mats and 0.65 kg m^{-2} for used mats. Mass of mineral wool saturated with water was 15-16 times higher comparing to dry mass. The higher value was observed for the mat used in crop production (Table 1). For the Cultilène® mats a significant increase in bulk density and a decrease in total porosity after approx. 6 months of plants cultivation was also observed by Nowak (2010).

Table 1. Water absorption of fresh and used mineral wool

Mineral wool	Dry mass [g]	Wet mass (partial immersion) [g]	Wet mass (full saturation) [g]
Fresh	118.75	702.72	1839.81
Used	118.75	770.50	1899.72

Source: Own study

Leachability was also higher in case of the mineral wool waste. After 96 hours, water losses amounted 14.5% (Fig. 4). At the same time, water losses from new mat amounted 10.7% of retained water. Leachability after 44 days of observation increased to 80% and 60% for used and fresh mineral wool, respectively.

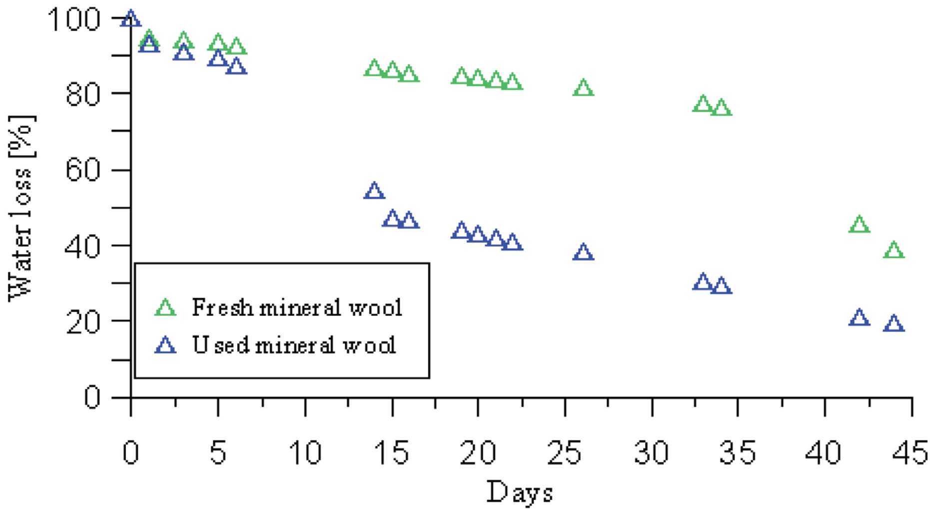


Figure 4. Leachability of the fresh and used mineral wool

Extensive green roof substrate used in the study complies with FLL (2008) guidelines. The maximum water capacity (pF = 0) remains within determined limits for green roof substrates, and the moisture content measured at matrix potential pF 1.8 exceeds the limit set at 20%. Total amount of water available for plants (AWP) was 13% while available water capacity (AWC), which is the amount of water that can be used by plants in biological processes (Bogacz *et al*. 2013), was 15%.

Tabele 2. Characteristics of mineral wool waste and extensive green roofs substrate.

Material	AWC	AWP	Moisture content measured at matrix potential pF, % vol.					
			0	**1**	**1.8**	**2.0**	**3.0**	**4.2**
Mineral wool waste	2.3	2.5	94	70	3.0	2.2	0.7	0.6
Extensive substrate	13	15	45	41	31	29	18	16

Source: own study

Mineral wool waste tested in the study does not compile with FLL (2008) guidelines and should not be use as the only medium supporting plant growth in green roof construction. The moisture content at pF 1.8 does not exceed the limit set at 20%, what means that it is too little air in it (Fig. 5; table 2). However, in the case of artificial materials a container water capacity should be considered (Dyśko *et al.* 2012; Jaroszuk-Sierocińska. 2007).

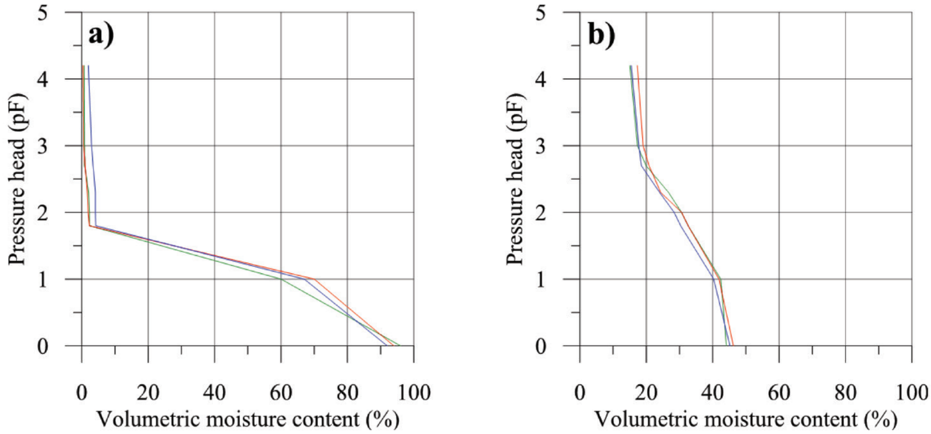


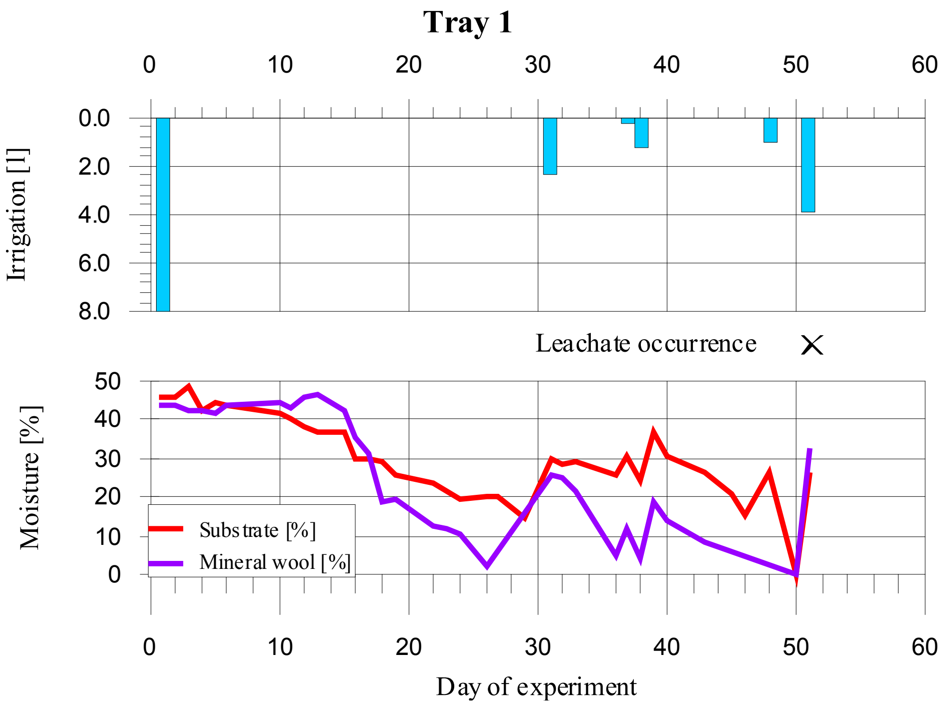
Figure 5. The pF curves characteristics of: a) mineral wool waste, b) extensive green roof substrate.

Characterising plant substrates, moisture content at pF=1.0 is essential. Dyśko *et al.* (2012) showed that the maximum water capacity (pF=0.0) for mineral wool was 92%, than water capacity has decreased in inverse proportion to the pF value. In this study moisture content at pF=1.0 was 79%. Jaroszuk-Sierocinska (2007) at the water content corresponding to pF=2.0 (-9.81 kPa) indicated that irrigation is recommended. For such pF in natural soils usually we have the best condition of water saturation. It has been found that the container water capacity crucial for the production on mats and easily accessible to the plants occurs at pF=1.0 to pF=2.0 (-0.98 to – 9.8 kPa). In mineral wool waste the value of water content at pF range 1.0-2.0 was large and amounted to 67.8%. In contrast AWP, the most important in the field production, was very small and amounted to 1.5%. Many studies (Fonteno 1988, Argo 1998, Jaroszuk-Sierocińska 2007) indicates that in case of plants cultivation on mineral wool, this type of substrate keeps the water against gravity at a potential corresponding container water capacity, which depends on the size and shape of pots, cubes or mats.

Evaluation of the usefulness of used mineral wool in green roof construction

The tray planted with *Lysimachia punctata* (tray 1) was characterised by higher moisture of the substrate than of the mineral wool waste. The largest differences in moisture was observed after 10 days without irrigation. The difference between the mat and substrate moisture reached 20% (Fig. 6a).

In tray 2 (*Jovibarba sobolifera*) the moisture of the extensive substrate and mineral wool were similar. Moisture distribution may be associated with evapotranspiration and water requirements of the plant.



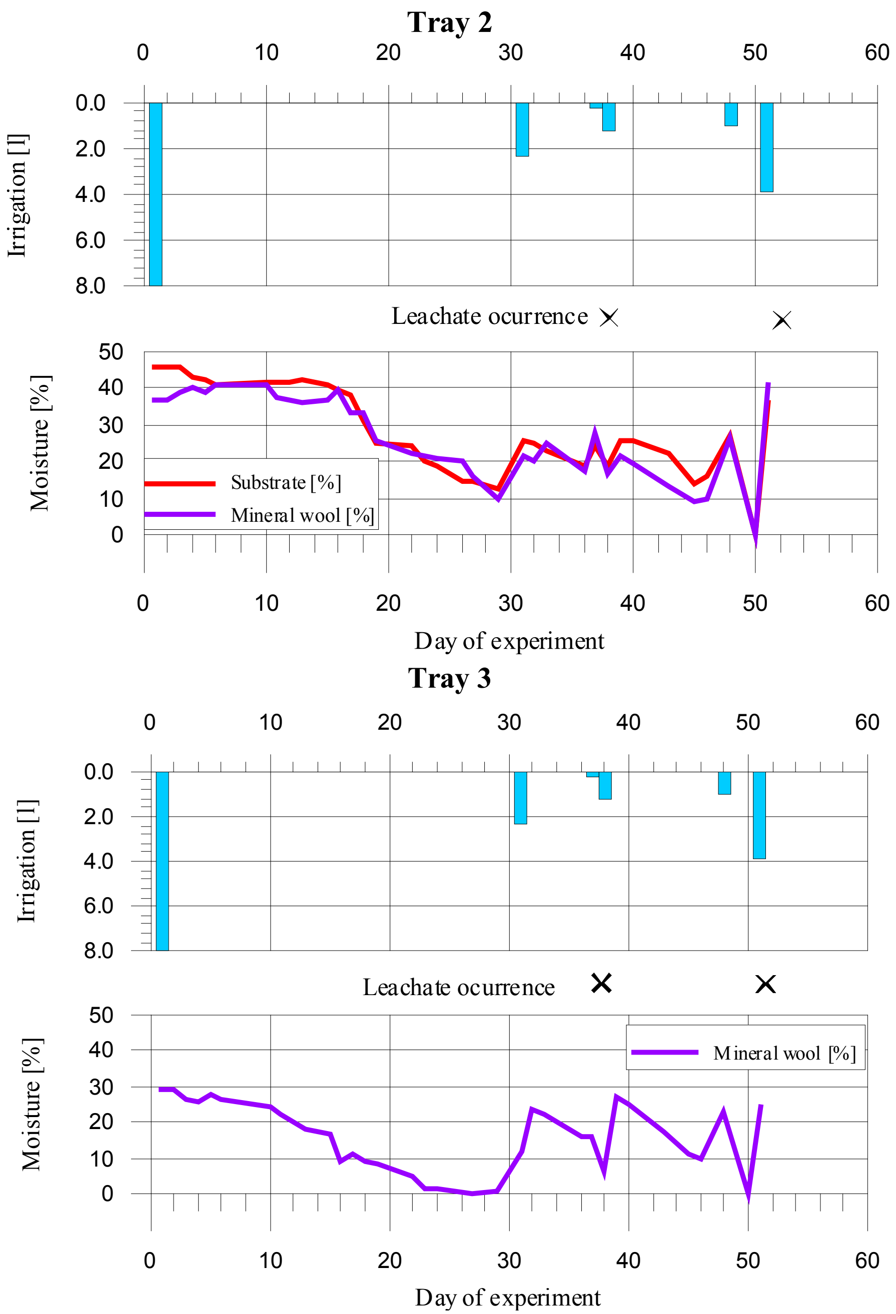


Figure 6. Changes in moisture of substrate and mineral wool on the background of rain simulation and leachates.

During the experiment 6 rainfall were simulated on each tray, however the leachate was not obtained together with all irrigations. In case of tray 1 only one leachate occurred, on tray 2 and 3 leachates were observed twice. All leachates were collected, the volume measured and samples were analysed for $P\text{-}PO_4$ concentration. Concentration of $P\text{-}PO_4$ in leachate varied from 0.31 to 3.10 mg dm^{-3}. Comparing to concentrations reported in literature for greenhouse runoff e.g. from 40 to 284 mg dm^{-3} (Prysay and Lo 2001, Yi *et al*. 2005) observed values are low. Observed loads of phosphorus were also diversified in different leachates and varied from 0.64 to 6.48 mg $P\text{-}PO_4$ kg^{-1}. In total loads of 3.65, 8.33 and 6.34 were observed for tray 1, 2 and 3 respectively. The results can be compared with the load of phosphorus obtained in preliminary leachate tests. From the test with 5 samples of mineral wool (10 g each) soaked in 500 ml of tap water, total load of phosphorus was estimated on 19.79 ±8.97 mg $P\text{-}PO_4$ kg^{-1}. In small column experiment irrigated with tap water total load of phosphorus was higher, and amounted 30.49 mg $P\text{-}PO_4$ kg^{-1}. Those results shows, that phosphorus content in used mineral wool is high and unevenly distributed in tested mats. This indicates that mineral wool can be a significant and long term source of phosphorus in green roof runoff. Research conducted by Kohler *et al.* (2002) and Karczmarczyk *et al*. (2012) have shown that the outflow of phosphorus from green roof substrates decreases with time. It is connected with the plant uptake and leaching. However, in case of mineral wool used for greenhouse cultivation of tomatoes phosphorus content is high and poses a serious threat to quality of green roof runoff receivers.

The study of physical properties showed that used mineral wool does not rot and is absorbable. Unfortunately, after re-drying mat was vulnerable to crushing which can contribute to clogging of drains if implemented in green roof construction. Layers of green roof are exposed to continual operation of meteorological conditions (rain, snow, frost), which may also contribute to changes of the physical properties of the mineral wool.

CONCLUSIONS

1. The physical properties of the mineral wool used for greenhouse tomatoes cultivation are different from characteristics of raw material, e.g. leachability after 44 days of observation increased to 80% and 60% for used and fresh mineral wool respectively.
2. The water sorption (pF) of used mats make it useless as an independent medium for the development of vegetation on the green roof. However, mineral wool may be an additional reservoir of water, especially on the extensive roofs.

3. The measurements showed a slight difference between the moisture in the trays with plants. Mineral wool loses the water in the higher rate than extensive green roof substrate.
4. The content of phosphorus in leachate from used mineral wool derived from greenhouse cultivation excludes its use as a material for green roofs construction, if the runoff is discharged into water bodies.

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