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*Original Research*

# Estimation of Structure and Water and Air Properties of Grodan Rockwool Waste after Production Cycle

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### Abstract

This paper focuses on the description of the structure and water-air properties of Grodan rockwool removed from the greenhouse after one production cycle of tomato. After removal from the greenhouse, the rockwool contained a lot of roots, the result of which was a considerable level of organic matter in the waste material, at 9.0 g/100 g. The analyses were conducted on rockwool crushed into scraps measuring 5×5, 2.5×2.5, and 1×1 cm. The used rockwool compared to new rockwool displayed a decrease in the container water capacity at water potential state of -0.98 kPa, and an increase in the field water capacity at water potential values of -9.81, -15.54, and -30.99 kPa. The highest gravimetric and volumetric water capacity at water potential of -9.81 kPa was noted for rockwool fragmented in large scraps, and at water potential values of -15.54 and -30.99 kPa for rockwool crushed into medium scraps. These changes are favorable from the viewpoint of the possibility of utilizing waste rockwool for soil reclamation.

**Keywords:** rockwool, water-air properties, soil reclamation

## Introduction

Rockwool is a substrate commonly used in the production of plants under shelters. Kaniszewski [1] reports that the area of cultivations in rockwool in Poland is estimated at 1,300 ha, and the annual requirement for the substrate amounts to approximately 10 million growth mats. The fundamental advantage of inert substrates, among which the leading role is played by rockwool, is the maintenance of optimum and stable water-air conditions for the root environment [2, 3]. The use of rockwool largely contributes also to a reduction in the use of peat as a horticultural substrate, which is highly important from the viewpoint of the need to protect peatland ecosystems [4, 5].

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A serious problem related with the use of rockwool in cultivations with an open fertigation system is drainage water penetration into the soil in the greenhouse or its vicinity. That causes increasing contamination of ground and surface waters with chemical agents, which constitutes a notable ecological hazard [2, 6, 7].

After 1-3 production cycles, rockwool has to be replaced with fresh material due to the deterioration of its physical properties, consisting primarily of an increase of the volumetric porosity and a reduction in total porosity [8, 9]. As opposed to organic substrates, the utilization of rockwool after its removal from the greenhouse is a very serious problem [10, 11]. Rockwool does not undergo degradation, which vastly hinders its utilization. One of the methods of re-using waste rockwool mats is their fragmentation and application for the reclamation of heavy soils or soils degraded by mining [12, 13]. Research results obtained by Baran [14] demonstrate that the application of waste mineral wool, after the production cycle in horticultural cultivations, for the remediation of degraded soil notably improved the water properties of the soil. Gilewska [15] is of the opinion that the cheapest and the simplest method of utilization of waste rockwool after its production cycles is its use in the reclamation of soils built of cohesive formations. Another problem is the utilization of fragmented rockwool, a waste material in the production of growth cubes. Dubský and Šrámek [16] report that in peat substrates or mixtures of peat with bark or compost, 35% (v/v) of peat can be substituted with rockwool shreds without any deterioration of substrate quality.

In the estimation of the applicability of waste rockwool for the improvement of the physical status of degraded soils, note should be taken of the fact that the basis for the characterization of the water-air properties of horticultural substrates in container cultures comprise parameters other than those relating to soils under field conditions [17]. In the case of horticultural substrates it is primarily the value of the container water capacity which, for a container with a height of 20 cm, corresponds to water potential value of -0.98 kPa, and the retention of water most easily available for plants, within the water potential range from -0.98 kPa to -9.81 kPa. For soil the most important parameters is the field water capacity corresponding to, depending on the depth of the ground water table, the water potential values of -9.81, -15.54, or -30.99 kPa. The basic retention determined for soils is the retention of water available for plants, within the range from the field water capacity to the permanent wilting point, i.e. -1,554 kPa. The most important parameter characterizing the air properties of horticultural substrates is the container air capacity (at the state of container water capacity), while for soils it is the field air capacity (at the state of field water capacity).

Due to the differences in the requirements concerning the physical properties of horticultural substrates and soils, the estimation of the possibility of utilization of waste rockwool for the reclamation of soils cannot be based only on information related to rockwool as a horticultural substrate. The present study provides a characterization of the water properties of mineral wool after the production cycle, taking into account the energy status of water under the conditions of the soil environment.

## Method of Research

Our study was concerned with the structure, bulk density, and water-air properties of Grodan mineral wool removed from the greenhouse of the Department of Cultivation and Fertilization of Horticultural Plants, University of Life Sciences in Lublin, after the production cycle from February to October of tomato (*Lycopersicum esculentum* Mill., cv. 'Admiro F1'). The tomato was grown on mats with size of 100×15×7.5 cm, two non-grafted plants per mat. The post-production wool was characterized by organic matter content of 9 g/100g, $pH_{H_2O}$ 6.2, $pH_{KCl}$ 5.9, and cation exchange capacity of 34.9 cmol(+)/kg. The study involved the use of 6 waste mats. The wool was prepared for the tests by cutting it into scraps of various sizes. Two mats were fragmented into large scraps of about 5×5 cm, two into medium scraps of ca. 2.5×2.5 cm, and two into small scraps of about 1×1 cm.

Samples for structural analyses were prepared from both small and large scraps of the rockwool. They were placed loosely in metal containers with dimensions of 8×9×4 cm. Samples prepared as above were saturated with a solution with the following composition: polyester resin Polimal-109, monostyrene, methyl ethyl ketone peroxide Luperox® GZ-S, and cobalt naphthenate (III). The impregnation was conducted in a vacuum dryer under pressure of 27-33 hPa. Resin polymerization lasted for about 6-10 weeks. The hardened blocks were then cut into slices 1 cm thick. The surfaces obtained in this way were smoothed and polished using corundum powders and abrasive papers of various grain sizes, from 80 to 1000, and polishing paste. The non-transparent one-sided polished sections were scanned at resolution of 600×600 dpi, in color mode, using an Epson Perfection 1200 Photo scanner.

The next stage of the study comprised the determination of water characteristics of rockwool within the range of potential values from 0 to -49.03 kPa, with the Richards method, in low pressure chambers on porous ceramic plates manufactured by Eijkelkamp. Rockwool scraps were placed in metal cylinders of 100 $cm^3$ in volume. Samples were prepared in 12 replicates for each size group of rockwool scraps. Assays of water content were performed for the following states of water potential: -0.098, -0.98, -3.10, -9.81, -15.54, -30.99, and -49.03 kPa. Values of water retention were calculated for the following ranges of water potential: from -0.098 to -0.98 kPa, from -0.98 to -9.81 kPa, and below -9.81. The results were expressed in g/100 g and $cm^3/100\ cm^3$.

The specific density of rockwool was determined using the pycnometric method. Bulk density was determined with the thermogravimetric method, on the basis of the ratio of the mass of material dried at 105ºC to the initial volume of the substrate (100 $cm^3$). The results were given in $Mg \cdot m^{-3}$. Total porosity was calculated on the basis of the specific density and the bulk density values. Air capacity at water potential states of -0.98, -9.81, -15.54, -30.99, and -49.03 kPa was calculated as the difference between the total water capacity (-0.098kPa) and water content at a given state of water potential. The results were given in $cm^3/100\ cm^3$.

The results obtained were compared with data characterizing the physical condition of new wool [3] and processed statistically with the method of one-factor analysis of variance.

The content of organic matter was assayed with the method of roasting at 550ºC. The sorptive properties were determined with the method of Kappen. The reaction was assayed with the electrometric method.

## Results and Discussion

The structure of rockwool waste after production cycle was the effect of several factors – the spongy structure imparted to the rockwool in the process of production of growth cubes, penetration by plant roots, and compaction in the course of use in the greenhouse, and finally fragmentation during the preparation of the scraps (Figs. 1 and 2). When the rockwool was removed from the greenhouse it contained a large amount of roots, the result of which was the notable content of organic matter in the waste material, at 9.0 g/100 g. Root sections in various planes can be seen in the photographs, in the form of numerous light elements. The fragmentation of the material during the preparation of the scraps, and the random arrangement of the fragments, caused the elimination of the regular spatial network of fibres characteristic of fresh wool, which is best seen in Fig. 2, where the rockwool scraps have the dimensions of 1×1 cm.

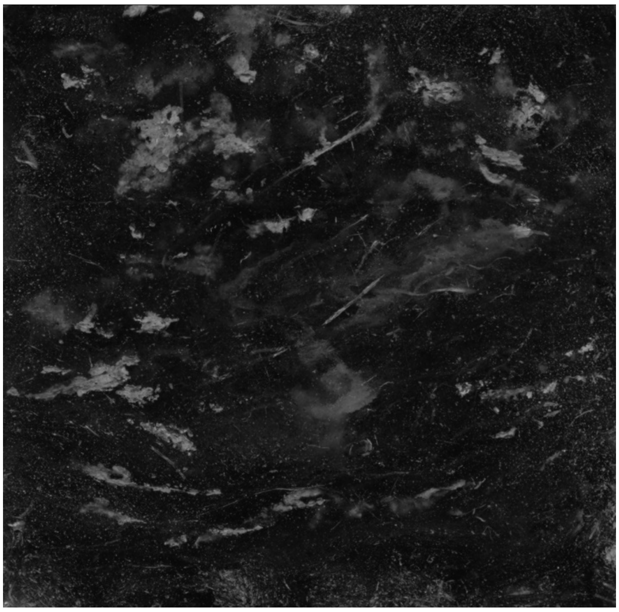

Fig. 1. Structure of the rockwool waste (large scraps 5×5 cm in size). Image size 8×9 cm.

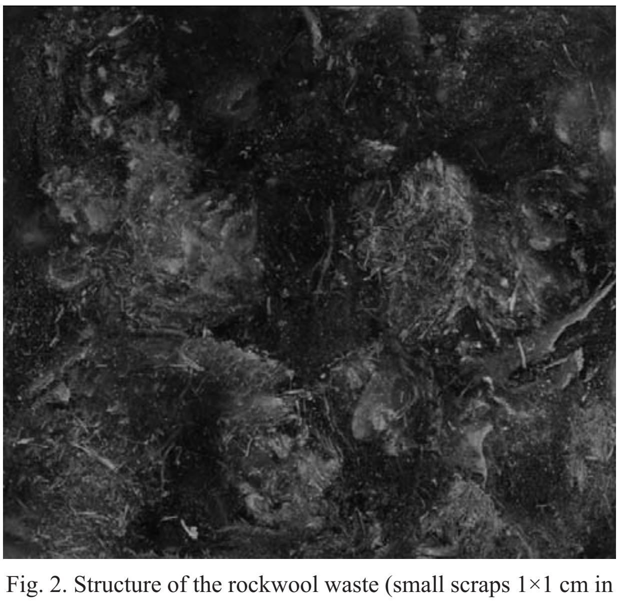

Fig. 2. Structure of the rockwool waste (small scraps 1×1 cm in size). Image size 8×9 cm.

Table 1. Particle density, bulk density, and total porosity of rockwool.

| Rockwool | Particle density | Bulk density | Total porosity |
|---|---|---|---|
| | $Mg \cdot m^{-3}$ | | $cm^3/100\ cm^3$ |
| Waste large scraps | 2.67 | 0.12 | 95.4 |
| Waste medium scraps | | 0.13 | 95.1 |
| Waste small scraps | | 0.11 | 95.8 |
| Fresh | 2.85 | 0.08 | 97.1 |
| $LSD_{0.05}$ | – | 0.018 | 0.69 |

The specific density of rockwool waste after production cycle was 2.67 $Mg \cdot m^{-3}$, while bulk density in the case of material fragmented into large scraps was 0.12 $Mg \cdot m^{-3}$, that of material fragmented into medium scraps 0.13 $Mg \cdot m^{-3}$, and into small scraps 0.11 $Mg \cdot m^{-3}$. As a result, the total porosity values formed a narrow range of 95.1-95.8 $cm^3/100\ cm^3$ (Table 1).

The total water capacity (-0.098 kPa) expressed in g/100 g was the highest in the case of the large scraps of rockwool, 767.5 g/l00 g (Table 2). For the medium scraps the value of that property decreased and amounted to 672.9 g/100 g, while for the small scraps it was slightly higher, at 687.8 g/100 g. At water potential state of -0.98 kPa (container water capacity) the amount of retained water was very high and decreased with increasing levels of fragmentation of the rockwool, the corresponding values being 686.3 g/100 g, 545.3 g/100 g, and 508.0 g/100 g.

After decreasing the water potential value to -3.10 kPa, a decrease was noted in the weight water capacity, though it was still very high: large scraps 534.4 g/100 g, medium scraps 464.5 g/100 g, and small scraps 362.2 g/100 g. Only at water potential of -9.81 kPa (i.e. at a state corresponding to the field water capacity of the surface horizon of soil, when the ground water table is at the depth of ca. 1 m) was a radical decrease noted in the gravimetric water capacity. For the large scraps of rockwool the capacity at that water potential state was the highest and amounted to 145.9 g/100 g, while for the medium scraps it was 123.5 g/100 g, and for the small scraps 92.6 g/100 g.

Further decrease of the potential caused a considerably weaker lowering of the gravimetric water capacity. At the potential of -15.54 kPa (field water capacity at ground water table at the depth of ca. 1.5 m) the following values of the capacity were observed: large scraps 95.4 g/100 g, medium scraps 110.7 g/100 g, and small scraps 80.3 g/l00 g, while at the potential value of -30.99 kPa (field water capacity at ground water table at the depth of ca. 3 m) the corresponding values were 79.8 g/100 g, 99.6 g/100 g, and 72.3 g/100 g, respectively. Also at the potential state of -49.03 kPa the

Table 2. Weight water capacity of rockwool.

| Rockwool | Water capacity at potential | | | | | | |
|---|---|---|---|---|---|---|---|
| | -0.098 kPa | -0.98 kPa | -3.10 kPa | -9.81 kPa | -15.54 kPa | -30.99 kPa | -49.03 kPa |
| | g/100 g | | | | | | |
| Waste large scraps | 767.5 | 686.3 | 534.4 | 145.9 | 95.4 | 79.8 | 74.5 |
| Waste medium scraps | 672.9 | 545.3 | 464.5 | 123.5 | 110.7 | 99.6 | 92.2 |
| Waste small scraps | 687.8 | 508.0 | 362.2 | 92.6 | 80.3 | 72.3 | 63.1 |
| Fresh | 1240.0 | 1123.9 | 678.9 | 18.6 | 15.9 | 13.7 | 11.5 |
| $LSD_{0.05}$ | 123.48 | 105.57 | 51.65 | 103.12 | 67.70 | 61.67 | 58.90 |

Table 3. Volume water capacity of rockwool.

| Rockwool | Water capacity at potential | | | | | | |
|---|---|---|---|---|---|---|---|
| | -0.098 kPa | -0.98 kPa | -3.10 kPa | -9.81 kPa | -15.54 kPa | -30.99 kPa | -49.03 kPa |
| | $cm^3/100\ cm^3$ | | | | | | |
| Waste large scraps | 92.1 | 82.4 | 64.6 | 17.9 | 11.7 | 9.8 | 9.1 |
| Waste medium scraps | 85.3 | 69.3 | 59.3 | 16.3 | 14.6 | 13.2 | 12.2 |
| Waste small scraps | 77.2 | 57.1 | 40.8 | 10.6 | 9.2 | 8.3 | 7.3 |
| Fresh | 100.6 | 91.4 | 55.8 | 1.5 | 1.3 | 1.1 | 0.9 |
| $LSD_{0.05}$ | 3.97 | 4.65 | 5.33 | 12.58 | 8.44 | 7.74 | 7.49 |

medium scraps retained the largest amount of water, 92.2 g/100 g, while the large and the small scraps were lower at 74.5 and 63.1 g/100 g, respectively. Thus, under conditions of suction pressure typical for the soil environment the highest values of the weight water capacity were characteristic of the rockwool with the medium level of fragmentation.

In the case of the volumetric water capacity the relations were highly similar (Table 3). At potential value of -0.098 kPa the volumetric water capacity was very high, especially in material fragmented into large scraps. In such samples it amounted to 92.1 $cm^3/100\ cm^3$ and it was nearly equal to the total porosity calculated from specific density and bulk density. In the case of the medium and small scraps the values of the capacity were lower, at 85.3 and 77.2 $cm^3/100\ cm^3$, respectively. The container water capacity of the large scraps at -0.98 kPa was 82.4 $cm^3/100\ cm^3$, that of medium scraps 69.3 $cm^3/100\ cm^3$, and the small ones 57.1 $cm^3/100\ cm^3$. A strong drop in the water capacity took place at the state of field capacity of -9.81 kPa. For the large scraps the values of that property were only 17.9 $cm^3/100\ cm^3$, for the medium ones 16.3 $cm^3/100\ cm^3$, and for the small scraps 10.6 $cm^3/100\ cm^3$. With further decrease of the potential the lowering of the water capacity was slight, and the highest values were noted in the material fragmented into medium scraps.

Among the water retention ranges considered decisively dominant (from -0.098 to -0.98 kPa; from -0.98 to -9.81 kPa; and below 9.81 kPa), both in terms of weight and volume, was the water retention in the potential range from -0.98 to -9.81 kPa (Table 4). The value of that retention decreased with increasing fragmentation of rockwool. The highest retention was noted for the large scraps (540.4 g/100 g and 64.5 $cm^3/100\ cm^3$), lower for the medium scraps (421.8 g/100 g and 52.9 $cm^3/100\ cm^3$), and the lowest for the small scraps (415.4 g/100 g and 46.5 $cm^3/100\ cm^3$). In container production that is the most valuable category of water – water most easily available for plants, while under field conditions, especially with a deeper ground water table, it is gravitational water, unusable for plants.

The air capacity of rockwool waste after production cycle was very high, even at states of high saturation with water (Table 5). Within the range of high water potentials the highest air capacity was characteristic of the small scraps, and once the water potential decreased – of the large scraps. The container air capacity of the small scraps at -0.98 kPa was 20.1 $cm^3/100\ cm^3$, that of the medium scraps 16.0 $cm^3/100\ cm^3$, and of the large ones 9.8 $cm^3/100\ cm^3$. The field air capacity of the large scraps at -9.81 kPa was 74.2 $cm^3/100\ cm^3$, that of medium scraps 69.0 $cm^3/100\ cm^3$, and that of the small scraps 66.7 $cm^3/100\ cm^3$.

Compared to fresh rockwool, before the production cycle, a notable change took place in the physical properties of the rockwool after the production cycle. Fresh Grodan rockwool, as follows from studies by Jaroszuk-Sierocińska [3], was characterized by highly favorable physical properties from the viewpoint of horticultural pro-

Table 4. Water retention of rockwool.

| Rockwool | Water retention | | | | | |
|---|---|---|---|---|---|---|
| | From -0.098 to -0.98 kPa | From -0.98 to -9.81 kPa | Under -9.81 kPa | From -0.098 to -0.98 kPa | From -0.98 to -9.81 kPa | Under -9.81 kPa |
| | g/100 g | | | $cm^3/100\ cm^3$ | | |
| Waste large scraps | 81.2 | 540.4 | 145.9 | 9.8 | 64.5 | 17.9 |
| Waste medium scraps | 127.6 | 421.8 | 123.5 | 16.0 | 52.9 | 16.3 |
| Waste small scraps | 179.8 | 415.4 | 92.6 | 20.1 | 46.5 | 10.6 |
| Fresh | 116.1 | 1105.3 | 18.6 | 9.3 | 89.9 | 1.5 |
| $LSD_{0.05}$ | 40.52 | 150.57 | 103.12 | 3.32 | 12.9 | 12.58 |

Table 5. Air capacity of rockwool.

| Rockwool | Air capacity at water potential | | | | | |
|---|---|---|---|---|---|---|
| | -0.98 kPa | -3.10 kPa | -9.81 kPa | -15.54 kPa | -30.99 kPa | -49.03 kPa |
| | $cm^3/100\ cm^3$ | | | | | |
| Waste large scraps | 9.8 | 27.6 | 74.2 | 80.4 | 82.4 | 83.1 |
| Waste medium scraps | 16.0 | 26.0 | 69.0 | 70.7 | 72.1 | 73.1 |
| Waste small scraps | 20.1 | 36.4 | 66.7 | 68.0 | 68.9 | 69.9 |
| Fresh | 9.3 | 44.8 | 99.1 | 99.4 | 99.5 | 99.7 |
| $LSD_{0.05}$ | 3.32 | 4.84 | 12.32 | 8.48 | 7.87 | 7.59 |

duction. Noteworthy is the fact that the fresh rockwool had particularly high – ca. 1,105 g/100 g and ca. 90 $cm^3/100\ cm^3$ – retention of the most valuable category of water in container production, i.e. water in the range of potential values from -0.98 to -9.81 kPa. That was determined by the spongy structure of the rockwool, achieved through the rock fibres compression in such a way that they formed a multi-layered network with very high porosity and a large content of macropores. Compared to fresh rockwool, in the post-production rockwool a notable decrease was observed in water capacity at states of high water potential, from -0.098 kPa to -3.10 kPa (Fig. 3). In consequence, the gravimetric retention of water most easily available for plants decreased by about 50-60%, and the volumetric retention by ca. 30-50%. This supports the opinions that changes taking place in rockwool during plant cultivation, resulting from the systematic irrigation, fertilization, and the impact of plant roots, lead to the degradation of its physical properties, and thus necessitate the replacement of the substrate.

The differences between the values of physical properties were very often statistically significant, both between the waste and new mineral wool and between scraps of different sizes. In the case of the water capacity, by weight and volume, within the range of high water potentials (from -0.098 to -3.10 kPa) the new wool almost always displayed higher values than all the kinds of waste wool. After lowering the water potential to -9.81 kPa the water capacity of the new wool was significantly lower than that of the large and medium scraps. Significant differences with relation to the size of the scraps appeared at states of high potential – for the gravimetric moisture those were potentials of -0.98 and -3.10 kPa, while for the volumetric moisture also the potential of -0.098 kPa (Tables 2 and 3). The gravimetric and volumetric retention of the most valuable category of water for container cultivation, from -0.98 to -9.81 kPa, was always significantly lower in the waste wool than in the new wool, while the retention of water useful in field conditions, below -9.81 kPa, was significantly lower in the new wool than in the large and medium scraps of waste wool (Table 4).

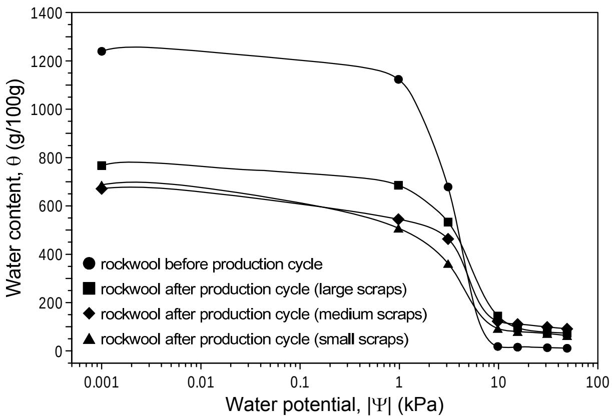


Fig. 3. Moisture characteristics curve of rockwool before and after production cycle.

The air capacity of new wool was significantly lower than that of the medium and small scraps only at the water potential state of -0.98 kPa, i.e. the container water capacity. Beginning with the potential of -3.10 kPa the air capacity of new wool was always significantly higher than that of the waste wool. At high states of water potential (-0.98 and -3.10 kPa) the air capacity of the small scraps was significantly higher than that of the large and medium scraps, while at low states of the potential (-15.54 kPa and below) the air capacity of the large scraps was significantly higher than that of the medium and small scraps (Table 5).

It should be noted that under field conditions water in the range of high potentials rapidly migrates, under the effect of gravity, from the surface zone of the soil into the depth of the pedon, and thus, opposite to greenhouse production on growth mats or cubes, it is unusable for plants. At the potential state of -9.81 kPa fresh rockwool was characterized by water capacity of only about 18 g/100 g [3]. In the rockwool waste there took place a shift in the amounts of retained water toward lower potentials, and a decisive increase in field water capacity. For potential of -9.81 kPa, in the case of the large scraps the increase was eight-fold, for the medium scraps – nearly seven-fold, and for the small scraps – five-fold, which is favorable for the soil environment as that water, retained by capillary forces, is available and usable for plants.

The application of waste rockwool may, therefore, effectively contribute to an improvement of the water relations of soils, especially degraded and reclaimed soils, which is indicated by the results of field experiments [12, 14]. However, it should be kept in mind that this is not an effect of the mineral material as such, but largely of the organic residues introduced with it, remaining in the substrate after the production cycle. Taking into account that air conditions dominate in waste rockwool after production cycle, it can also be applied for the reclamation of compacted soils.

## Conclusions

1. The changes in the structure and physical properties taking place in rockwool during horticultural production are favorable from the viewpoint of the possibility of applying that material for the reclamation of soils.
2. The application of waste rockwool brings into the soil considerable amounts of roots of the crop plants grown, which has a positive effect on the balance of organic matter in the soil environment and on the physical status of the soil.
3. Compared to fresh rockwool, waste rockwool after production cycle was characterized by reduced container water capacity at water potential state of -0.98 kPa, and increased field water capacity at potential states of -9.81, -15.54, and -30.99 kPa. Rockwool fragmented into large scraps displayed the highest gravimetric and volumetric water capacity at water potential of -9.81 kPa, while at potentials of -15.54 and -30.99 kPa the highest water capacity was noted for rockwool fragmented into medium scraps.
4. In spite of the increase in water retention ability under field conditions, air capacity dominated decisively in the waste rockwool, which supports the opinions about its applicability for the reclamation of heavy soils and strongly compacted ones.

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