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Using Sheep's Wool as an Additive to the Growing Medium and its Impact on Plant Development on the Example of *Chlorophytum comosum*

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ABSTRACT

The paper presents the results of the research on the possibility of using sheep wool in the form of wool waste as an additive to the soil for plants. *Chlorophytum comosum* was selected for the research, as a plant that is very easy grow. The wool was introduced into the soil in two ways: in the form of a compact layer on the bottom of the pot (sample A) and in the form of an even mixture with soil (sample B). The research focused on the impact of the wool and method of its deployment on soil humidity. The research showed that even mixing of the fibers with the soil provided plants with the access to water and prevented water evaporation. In addition, the presence of wool in the whole soil volume influenced the formation of *Chlorophytum comosum* root system. Scanning electron microscopy (SEM) together with elemental analysis (EDS) enabled analyzing the relationship between the method of mixing wool fibers with the cultivation substrate and the degradation on the fiber surface. The studies have shown that single fibers dispersed in the soil (sample B) undergo decomposition easier than the fibers placed on the bottom of the pot (sample A). The decomposition consisted in damage to the epidermal layer and a decrease in fiber thickness from 35.8 μm for the reference sample (X) down to 29.4 μm for sample B. Furthermore, the studies using the EDS probe confirmed that the wool keratin content decreased from 30.5% (for sample X) to 22.3% (for sample B), due to degradation.

Keywords: sheep wool, cultivation of plants, biodegradation.

INTRODUCTION

The rapidly growing number of people on Earth forces food producers to use the measures that increase the yield of plants. Very important examples are various types of soil additives used in cultivation. These are primarily mineral and organic fertilizers, as well as other substances, such as polymer hydrogels increasing the water capacity of the soil, or plant protection products.

Due to the growing interest in biodegradable materials, products made of natural materials, thus not burdening the natural environment, have become very popular in recent years (Astner et al. 2019). There are many scientific reports on the attempts to use biopolymer composites as mulching and cover materials or for the production of the seedling containers that are biodegradable in soil (Zawiska and Siwek 2015). The period of their degradation ranges from one month to several months, depending on the type of biopolymer and its molecular weight (Puchalski et al. 2018). Most of these materials meet the basic assumptions, which are: improvement of plant growth conditions, as well as increased yield and material biodegradability. It is also worth mentioning that these materials are compostable, but not always biodegradable. They are only decomposed by microorganisms under appropriate thermal conditions and at sufficiently high humidity (Puchalski et al. 2019).

From an economic point of view, using existing materials, in particular natural waste materials, rather than synthesizing and producing new, biodegradable polymer materials it is most cost-effective solution. The additives made of textile waste, which include the products made of synthetic and natural fibers, are very popular. Among textile waste based on natural fibers, one can distinguish polysaccharide fibers (e.g. cotton, linen, hemp, jute) and protein fibers (e.g. wool, silk). A common feature of all natural fibers is their degradation under the influence of various environmental factors. The speed of the biodegradation processes of fibrous materials is greatly influenced by the degree of their fragmentation. The finely fragmented material has a larger surface on which microorganisms can multiply (Tokiwa and Calabia 2006) (Pérez et al. 2002).

Cellulose fibers are degraded under the influence of microorganisms, leading to the formation of sugars, which form a medium for bacteria and fungi. In the case of polysaccharide fibers, the degradation time is long and depends on the length of the fibers and their degree of crystallinity. Shaari et al. [2020] developed a method of producing biodegradable containers from a blend of cotton and viscose fibers that biodegraded over a period of 60 days (Shaari et al. 2020). Another example of the use of cellulose fibers as a multifunctional mulching material are the nonwovens developed by Özen›s team [2018], which contained potassium nitrate, and owing to the use of poly(vinyl alcohol) the effect of prolonged release of fertilizers was obtained (Özen, Okyay, and Ulaş 2018). Mulching cellulose nonwovens containing fertilizers were also developed and tested (Gabryś et al. 2021).

In the case of wool fibers, the degradation process is more complicated. Wool degradation is closely related to the type of fibers used. Raw wool is more difficult to degrade, because the fibers are covered with a layer of suint and their surface is not damaged by the processing. In the case of mechanically treated wool, on the other hand, the outer layer of the fiber – cuticle – is destroyed, making it susceptible to enzymatic hydrolysis under the influence of microorganisms. While the wool fibers degrade, animal protein is converted into simple substances that are introduced into the soil. Wool is characterized by a high content of nitrogen, phosphorus and potassium, as well as micronutrients such as calcium, magnesium, iron and sulfur, which are made available to plants in an easily digestible form. That is why, fibrous materials of animal origin are successfully used in the cultivation of green plants, which are characterized by the highest nitrogen demand (Ikoyi et al. 2020) (Cavalcante et al. 2020)PB, Brazil. A randomized block design with three repetitions and 14 treatments originated from a Baconian matrix was adopted. Reference doses were 50:300:150 kg·ha^{-1} of N, P2O5 and K2O. At the end of the study, plant height, stem diameter, number of leaves, leaf area, total seed number, total seed weight, total fruit number and oil production per plant were evaluated. On average, the nitrogen dose of 150 kg ha-1 led to adequate values of growth and yield variables. For plant growth, 300 kg ha-1 of phosphorus should be applied, since the differences in the increase of growth variables between this dose and the highest ones estimated by the equations were very small; for castor bean production, the best applied dose was 600 kg·ha^{-1} of phosphorus. The application of potassium increased the leaf area, number of seeds and production of oil, and the best dose was 300 kg·ha^{-1}. Phosphorus was the nutrient that promoted the highest production of oil per plant (92.40 g. In addition to its fertilizing effect, wool improves the structure of the soil, because it easily absorbs water, which is released during drought periods.

All these features of wool have been known for a long time; however, the progressive chemicalization of agriculture and the intensification of cultivation resulted in this type of organic fertilizer being forgotten. Nowadays, wool is experiencing renewed interest and commercial geotextile nonwovens (Covelana) can be found on store shelves for use in broadly understood agriculture or gardening. In addition, wool-based ecological fertilizers (Fertilan L, Compo Bio) can be purchased. Kemafil-type products, filled with wool fibers, have been developed and tested in detail (Broda et al. 2016).

The paper describes the research on the use of wool fibers in the form of waste (wool dust) as an additive to the substrate used in the laboratory cultivation of *Chlorophytum comosum*. The plant with decorative white-green leaves selected for the research belongs to the group of plants that are very resistant to cultivation conditions. Wool in the soil was used in two ways: in the form of an even mixture with the soil and in the form of a compact layer at the bottom of the pot. The purpose of the research was to determine the effect of wool addition and its distribution in the substrate on soil moisture and the structure of the root system of *Chlorophytum comosum*. Moreover, the relationship between the method of application of wool fibers to the growing medium and the degradation on their surface was analyzed.

EXPERIMENT

Materials

Chlorophytum comosum, a popular potted plant that is very easy to grow, was selected for the research. The main part of the habit of this plant, characterized by the white-green color of the leaves, is above the ground. Moreover, *Chlorophytum comosum* is resistant to both insufficiency and excess of water in the soil, which constituted the main area of the research. The substrate for growing plants was COMPO BIO horticultural universal soil (COMPO GmbH, Germany). Wool dust, which is a waste from industrial processing of wool (spinning and weaving) was used in the study. The wool component was obtained from Rytex, a company based in Bielsko-Biała.

Figure 1. Sheep wool used in the experiment

A photograph of the wool dust used in the experiment is shown in Figure 1. They are very short staple fibers with an average length of approximately 1 cm.

Research methodology

Three research groups of plants took part in the experiment, 10 plants in each group. The first research group of plant samples (0) was a control group, and the plants grew only in the substrate itself. The second group (A) included the plants growing in the substrate with 5.7 g of wool placed at the bottom of the growing container. The third group (B) comprised the plants growing in the substrate mixed evenly with sheep wool throughout its entire volume (Table 1). The plants were grown in cultivation containers with a diameter of 120 mm and a capacity of 0.7 dm^3, and the amount of wool used in the container with the plant was 8.1 g/dm^3. Cultivation was carried out for a period of 12 months.

All test plants were watered in the same way: once a week through the flood system (at the bottom of the pot) with 100 cm^3 of water per each plant. The substrate moisture content was tested using a MMM tensiometer equipped with a vacuum gauge (Table 2). The measurement of the suction force by the tensiometer consists in measuring the negative pressure in the range from 0 to 600 hPa. The green color (100–350 hPa) is the optimum range of humidity for growing the majority of plants.

The plants were grown in a laboratory, where the temperature and air humidity were variable and dependent on the season of the year and heating.

Table 1. Sample designation system with the descriptions

Sample designation	Sample description
0	Control sample, no wool added
A	Wool stacked on the bottom of the container
B	Wool mixed with the cultivation substrate

Table 2. Moisture scale on the tensiometer

Color	Vacuum [hPa]	Indication
Blue	0–80	Too wet
Blue-green	80–100	The soil is saturated with water, but is not too wet
Green	100–350	Optimum soil moisture
Green-orange	350–450	Onset of drought (irrigation is possible)
Orange	450–500	Apply irrigation
Orange-red	500–550	It is high time to irrigate
Red	above 550	Too dry - the stress caused by drought

After the end of the experiment, organoleptic tests of *Chlorophytum comosum*, which consisted in determining the degree of leaf coloring and the structure of the root ball, were carried out.

The surface morphology of the fibers was examined using a scanning electron microscope (SEM) (Thermo Fisher Scientific) at an accelerating voltage of 10 kV. Initially, the wool samples were coated with a 10 nm thick layer of gold using a Leica EM ACE 200 low-vacuum coater. In addition, local elemental analysis was performed using the same scanning electron microscope equipped with an EDS detector. Chemical composition tests were carried out on the samples not coated with gold, at an accelerating voltage of 15 kV. On the basis of the emission of characteristic X-rays, qualitative and quantitative analyses of wool samples were performed. Fiber diameter tests were performed with the use of the FiberMetric computer software. For these tests, 20 fibers were selected from the reference sample (X) and from each pot containing samples A and B. In order to make SEM pictures, the wool samples taken from the pots were dried and then the remnants of the substrate were removed.

RESEARCH RESULTS AND DISCUSSION

Initially, all plants were visually compared; the color of leaves, the amount of green mass and the root system analyzed. Figure 2 presents the photographs of the tested plants (individual samples: 0, A, B) at the beginning of the research and the same plants after 12 months of cultivation. After one year, a significant, almost uniform increase in green mass was visible in all three groups of the tested plants. There were no significant differences in plant structure and habit. All plants had full coloration, which is surprising, as the literature provides the examples of plants grown in the presence of wool gaining an intense green color (Broda et al. 2016). However, there were differences in the structure of the roots, as *Chlorophytum comosum* had grown a highly developed root system. After the research was completed, it turned out that the plants from the control sample (0) developed a lot of fine roots in the entire volume of the pot and a small amount of thicker roots closer to the bottom of the pot. The same shape the root ball was visible in samples A, but the number of thicker roots was much higher than in sample 0. Short roots supply the plants with water and mineral salts. It can therefore be assumed that the wool fibers placed at the bottom of the pot retain moisture, which is then slowly released to the plant roots, thus ensuring longer hydration. On the other hand, the samples of plants from group B, in which the wool was evenly mixed with the substrate, developed thick roots in the entire volume of the pots. Long roots grow quickly and attain considerable length. Their main function is to provide the plant with fixation in the substrate and to transport substances taken up by short roots. Thus, the structure of the root system of *Chlorophytum comosum* from research group B proves the presence of water and its access to the entire volume of soil.

Moreover, it was observed that the outer layer of the soil in the pots containing the plants from groups 0 and A behaves similarly, was moist immediately after watering, and then it dried quickly (1–2 days). The outer layer of soil in the B pots, on the other hand, retained moisture for 2–5 days (depending on the conditions in the laboratory).

All types of substrate, in addition to the visual assessment, were also tested using a tensiometer. On the day of watering, the device indicated green, i.e. the optimal humidity for all soil samples (0, A and B). Within 2 days after watering, for the pots marked as samples 0 (without wool) and samples A (containing wool dust at the bottom of the pots), the tensiometer indicated the onset of drought, i.e. a green-orange color, while, at the same time, it still indicated the optimal soil moisture for samples B. For the substrate fully mixed with wool fibers, the period of drought (orange) started about 5 days after watering the plants (depending on the conditions in the laboratory). The study shows that preparation of the substrate by thorough mixing it with wool dust provides plants with much longer hydration than introducing these fibers to the bottom of the pot only. Due to this effect, water does not evaporate from the soil as quickly as for samples 0 and A, and is available to the plants for a much longer period.

The surface morphology of the fibers was analyzed using a SEM microscope. In Figure 3, selected SEM microphotographs showing the structure of the fiber surface are summarized. The summary includes selected images of the initial (reference) wool sample (X), which was used in the study, as well as wool samples after

Figure 2. Photographs of plants at the start of the experiment (left) and after 12 months (right): 0 – control sample, A – wool sample on the bottom of the pot, B – wool sample mixed with the substrate

12 months of plant cultivation, taken from two research groups – A and B.

The microscopic SEM analysis (Fig. 3) provided a lot of valuable information on the processes taking place on the fiber surface. The initial fiber (X) had a characteristic structure typical of sheep wool. The epidermis covered with characteristic, tile-like scales was clearly visible. The wool sample from the bottom of the growing container (A) had a slightly different structure. The epidermis was partially degraded and the scales were barely visible. This proves that the environmental factors, including microorganisms, impact partial degradation of the outer layer of the fiber. The degradation process was very well visible in the case of sample (B). It covers not only the epidermal layer, but also the deeper core. It follows that the wool mixed with the cultivation substrate underwent faster biodegradation due to the larger surface of contact with the soil inhabited by microorganisms.

Wool is a protein fiber and has the chemical composition typical of animal proteins. It consists mainly of carbon, nitrogen, oxygen, sulfur; these elements were been selected to determine the changes in the qualitative composition of wool used in plant cultivation (Fig. 4). Wool keratin is degraded into amino acids under the influence of inorganic acids, bases, enzymes, elevated temperature and UV radiation (Broda et al. 2016). Nitrogen is the element that is the most important for green plants. By analyzing the elemental composition of the wool fibers used in the experiment, their degradation can be traced over time. The fiber surface of the wool control sample (X) contained 30.5% of nitrogen. However, after 12 months from the beginning of the study, the surface of wool sample A still contained large amounts of nitrogen – 25.6%. In the case of sample B (after one year of the study), the content of elemental nitrogen was much lower and amounted to 18%. It can be assumed that during the degradation of wool, the released nitrogen compounds were absorbed by

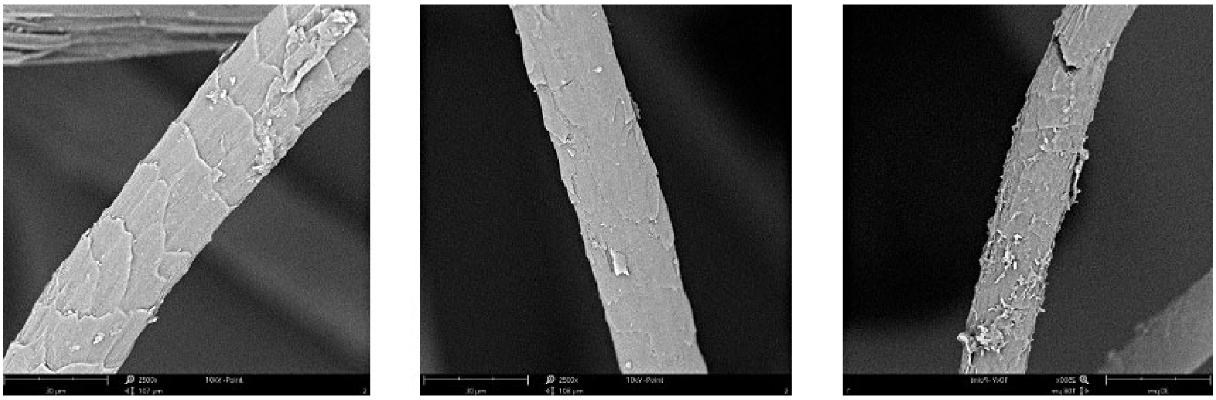

Figure 3. SEM microphotographs: X – reference wool sample used for the experiment, A – wool sample from the bottom of the pot, B – sample of wool mixed with the crop substrate

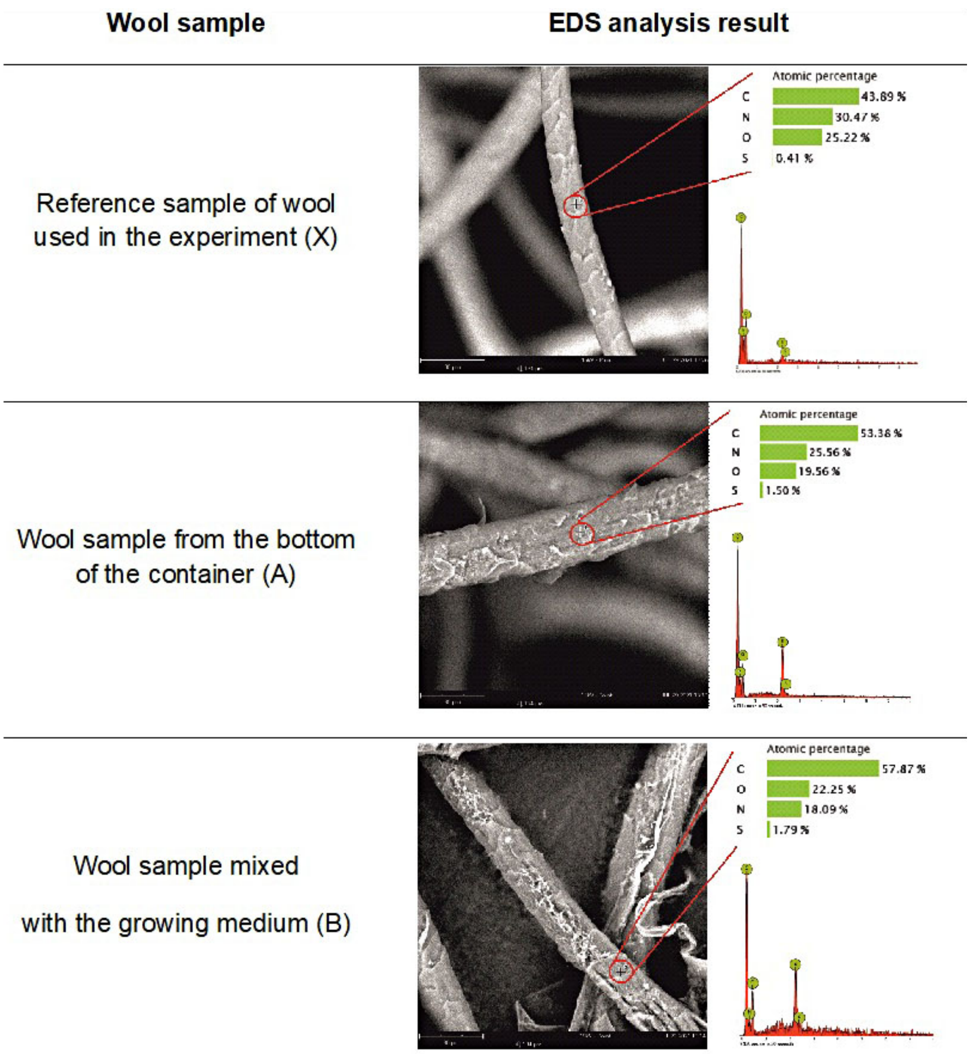

Figure 4. SEM microphotographs along with the results of EDS qualitative analysis

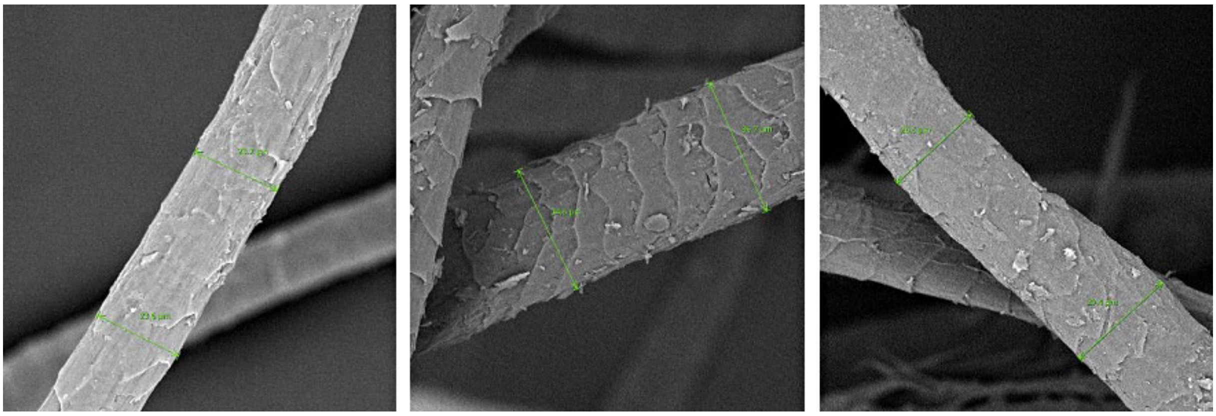

Figure 5. Example of the application of Fiber Metric software to determine the thickness of the fibers

Table 3. Thickness of the tested wool fibers

Sample	X	A	B
Fiber thickness [μm]	35.75 ± 0.76	31.05 ± 3.39	29.37 ± 0.50

the plant root system. When analyzing the loss of elemental nitrogen, it should be remembered that wool keratin in the first stage degrades into the so-called organic nitrogen, i.e. the peptide bonds break down, leading to the formation of amino acids. After this stage, under the influence of microorganisms, proper biodegradation takes place, leading to the formation of nitrogen compounds (NH_4^+, NO_3^-, NO_2^-), which are absorbed by plants (Broda et al. 2016).

A lot of information about the destruction processes taking place during degradation can be obtained by analyzing the thickness of the fibers. The initial fibers (X) and the wool fibers from samples A and B, were analyzed after the end of the experiment. For this purpose, the FiberMetric software was used (Fig. 5), and the obtained results are summarized in Table 3.

The thickness of the wool fibers used in the experiment ranged from 35.8 μm for the reference sample (X) to 29.4 μm for the fibers mixed with the substrate (B). Detailed analysis indicated that the fibers mixed with the substrate (B) had the smallest thickness, while the thickness of the fibers from the bottom of the growing containers (A) had only decreased by 11%. This proves that the complete mixing of the fibers with the substrate promotes their faster decomposition. The research showed that the results of the fiber thickness measurements confirm the qualitative analysis, which proves the occurrence of wool fiber degradation.

CONCLUSIONS

- The addition of short wool fibers to the arable land, introduced evenly and in the entire volume of the substrate, provides plants with the access to water and prevents water evaporation.
- The even mixing of wool dust with the soil influences the structure of the root system of *Chlorophytum comosum* which is based on the roots used for water transport.
- Scanning electron microscopy confirmed that the surface of the wool fibers, which were evenly dispersed throughout the entire volume of the substrate, was damaged in the highest degree due to the larger contact surface with the soil. Elemental analysis of wool fibers indicated that thorough mixing of wool with the growing medium guarantees its better decomposition into nutrients, which is confirmed by the loss of nitrogen from the surface of the samples.
- The biodegradation of wool is accompanied by its physical disintegration through the observed deformation of the epidermal layer and reduction of the thickness of the fibers.
- Organoleptic analysis of *Chlorophytum comosum* demonstrated a positive effect of sheep wool on the development, growth and appearance of plants.

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