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THE ROLE OF BIODEGRADABLE NONWOVEN FABRICS IN EFFICIENT SODDING OF EARTH STRUCTURES

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ABSTRACT

Aim of the study

Newly formed earth structures such as ski slopes are areas causing difficulties in attempts for efficient sodding since colonization with plants, where initial development and adaptation are hindered due to unfavourable climatic and soil factors. The main objective of the study was to demonstrate the feasibility of using nonwoven fabrics made from sheep's wool and waste poultry feathers on steep-gradient mountain slopes.

Material and methods

Biodegradable geotextiles can be used not only to protect seeds and soil from washout, but also to promote turf development and improve soil microbial quality. During the experiment, plant growth was monitored together with microbial frequency changes.

Results and conclusions

The results showed that the application of nonwoven fabrics after sowing a mix of grasses and clover had many advantages including the acceleration of seedling germination, improvement of plant initial development, and increase in the number of plants per square metre. The ultimate biostimulation effect was found to be strongly dependent on geotextile biodegradability, grammage and the fleece structure. The best yield was obtained with the nonwoven grammage within the range of 150–180 g · m^{-2}. The promotion of plant growth and, in particular, the development of the root system had a significant positive impact on the population of soil microbiota.

Keywords: sodding, soil microbiota, biodegradable geotextiles, mountain slopes

INTRODUCTION

The durability of earth structures such as dykes, escarpments, embankments, roadside drainage ditches, slopes or newly formed ski trails depends on the type of soil material used for their formation, its compaction and inclination. The presence of plants together with their root systems is a very important factor improving stability of the structures, limiting water loss and air erosion, and facilitating the creation of biologically active surfaces. However, the better the compaction and formation of the structures from soil material, the

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more difficult it is for plants to colonize their surface. It is therefore necessary to find solutions that facilitate the initial development of plants and enrich biological life of the soil. Biodegradable nonwoven fabrics with a high water holding capacity are considered useful for these purposes as they reduce soil erosion and retain rainwater essential for plant growth especially during the initial stages of development. Most of the commonly used nonwovens are made of synthetic polymers that have to be taken off after use, only to become a nuisance waste (Bonafe, 2020; Kacorzyk et al., 2021). Improper disposal of such fibrous materials, exposure to ultraviolet radiation, abrasion or oxidation can release microplastics into the environment. The pollution caused by microplastic particles is considered to be an emerging threat to biodiversity and to the proper functioning of ecosystems (Kopitar et al., 2022). In this context, the application of waste materials of natural origin rather than producing new ones, which follows a waste-to-product concept, appears the most cost-effective and environment-friendly approach (Broda et al., 2017). In the case of bio-based nonwoven fabrics, once the root system develops and full plant establishment is achieved, the geotextile material tends to gradually decompose and provide nutrients for growing vegetation. Textile waste such as cotton, linen or sheep's wool is of particular interest. By combining various fibers in varying proportions, it is feasible to obtain different grammage, structures, physical-chemical characteristics and, eventually, different degradation periods (Gabryś et al., 2021). Bird feathers obtained from slaughtered poultry have been considered as a suitable material for the improvement of nonwovens (Kacorzyk et al., 2021). One of the leading Polish companies produces 6 tons of feathers daily. This waste is typically processed into industrial "flour", even though the European Union (EU) has banned its use as an livestock food component (Jóźwik-Pruska et al., 2022). Feathers are primarily made up of β-keratin, a fibrous protein with excellent chemical and mechanical resistance. Their properties, such as high heat retention together with low weight, flammability and microporous internal structure, make feathers a valuable material with potential applications as thermal insulation, sound absorption, and filter layers (Fuller, 2015; Pasayev et al., 2018; Vilchez et al., 2020; Xu et al., 2022). In addition, due to high nitrogen content (13%), they may serve as a fertilizer in the agricultural sector (Vilchez et al., 2020).

In order to obtain a dense and durable turf, the use of a suitable plant composition is required. The best species for turfing in areas of problematic earth structures include: meadowgrass (*Poa pratensis* L.), red fescue (*Festuca rubra* L.), perennial ryegrass (*Lolium perenne* L.), and white conch (*Trifolium repens* L) (Herbich, 2000; Dembek et al., 2005; Kacorzyk and Kasperczyk, 2016). These plants form a good canopy and a low yield of aboveground mass, which reduces the cost of mowing and biomass removal (Koda et al., 2010; Kacorzyk and Kasperczyk, 2016). In turn, it should be noted that the soil microbiota plays a particularly important role in plant growth and soil quality improvement. The plant-microbe interaction is a mutually beneficial relationship. Microorganisms can stimulate plant growth and activate plant response to stress conditions through decomposition of organic matter, nutrient cycling, and the production of phytohormones (Meena et al., 2020, Mahatma et al. 2023, Maheshwari et al., 2023; Srinivasan et al., 2023). At the same time, plant roots have a significant positive impact on the prokaryotic microorganisms growth and development through secretion of various substances, including nutrients, vitamins, and oxygen into the rhizosphere (Odelade and Babalola, 2019). The number of bacteria in the rhizosphere is significantly higher than in the bulk soil (Li et al., 2019, 2020). For the case of soil microscopic fungi, it should be stressed that the abundance of these eukaryotic microorganisms is predominantly influenced by soil structure rather than by occurrence of plant species (Tkacz et al., 2020).

The main objective of the present study was to evaluate the possibility of the use of biodegradable nonwoven fabrics for covering newly formed ski slopes in order to provide better conditions for sodding and development of soil biological life. The tested fabrics were produced under laboratory conditions and compared with a commercially available industrial product serving as a control. Different weights, structures, feather content, and fineness were analysed to select the most effective variant. In order to establish the effect of innovative coverage materials on plant growth and soil microbiota development, the observations were carried out during two years of slope stabilization and turf formation.

MATERIALS AND METHODS

Biodegradable nonwovens were made from waste sheep wool and feathers obtained from poultry slaughterhouses. The tested variants differed in their composition, having various proportions of feathers and wool, grammage, and texture (Table 1). They were produced under the Intelligent Development Operational Program 2014–2020 supported by the Polish National Centre for Research and Development and implemented between 2018 and 2023 (Project "Ekopióro", 2018). Eight types of nonwovens were developed under laboratory conditions at the Łukasiewicz Research Network – Łódź Institute of Technology (cover numbers: 1–8), and the other two (cover numbers: 9–10) were industrial-scale products of Poltops Sp. z o.o., Żagań, Poland. The polymer cover no. 11 was a commercial agrotextile "Pegas Agro" manufactured by AGRIMPEX Sp. z o.o., Jarosław, Poland, and served as a non-biodegradable control.

Eleven types of nonwoven fabric covers were used in the field tests (Table 2), including ten biodegradable formulations (nos. 1–10) and one commercially available Pegas Agro control polymer (no. 11). The field experiment was set up in the beginning of May 2021, on the newly formed ski run at Jaworzyna Krynicka mountain located in Southern Poland (49°24'46"N 20°54'48"E, 1114 m above sea level). A more detailed information regarding the mountain geological formation is given elsewhere (Kacorzyk et al., 2021). The soil composition of the ski slope area was 50% dust, 32% sand and 18% clay, with chemical properties as follows: pH 6.04 (as determined in in 1 mol · dm^{-3} KCl), organic carbon content 14.2 g · kg^{-1} d.m. (dry matter), total N 1.1 g · kg^{-1} d.m., bioavailable forms of P, K and Mg 2.7; 95.2; 35.6 mg · kg^{-1} d.m., respectively (Figure 1A). The field test consisted of thirteen experimental variants, each carried out in three replications (Table 2). The plots of 18 m^2 each were sown with a seed mixture containing the following plant species: *Festuca rubra* L. – 30%, *Poa pratensis* L. – 30%, *Lolium perenne* L. – 20%, *Trifolium repens* L. – 15% and *Festuca pratensis* L. – 5%. Due to the difficult habitat conditions, the number of seeds was increased by 300% relative to the recommended standard values, i.e. 0.14 kg of seeds were used per plot. Mineral fer-

Table 1. Types of nonwovens manufactured for the purpose of the study (source: own elaboration)

No.	Nonwoven fabric symbol	Grammage (g · m^{-2})	Feather content (%)
1	Łódź TT I/1	95	30
2	Łódź TT I/2	137	40
3	Łódź TT I/1&2	110	32
4	Łódź TT II/1	123	30
5	Łódź TT II/2	149	40
6	Łódź TT 21 Ł	120	34
7	Łódź TT 21 C2	127	33
8	Łódź TT/21	184	40
9	Żagań I	115	30
10	Żagań II	95	26
11	Commercially available Pegas Agro polymer agrotextile	17	0

Table 2. Variants of the field experiment (source: own elaboration)

Variant symbol	Fertilization N40P30K50	Symbol of nonwoven used
A	–	–
B	+	–
C	+	Łódź TT I/1
D	+	Łódź TT I/2
E	+	Łódź TT I/1&2
F	+	Łódź TT II/1
G	+	Łódź TT II/2
H	+	Łódź TT 21 Ł
I	+	Łódź TT 21 C2
J	+	Łódź TT/21
K	+	Żagań I
L	+	Żagań II
M	+	Commercially available Pegas Agro polymer agrotextile

"+" – fertilization (details in text) was applied for the variant tilization was applied each spring at the following rates: nitrogen, 40 kg · ha^{-1} in the form of ammonium nitrate (34% N); phosphorus, 30 kg · ha^{-1} 1 in the form of superphosphate (40% P_2O_5), and potassium, 50 kg · ha^{-1} in the form of potassium salt (56% K_2O). All the fertilizers used were commercially available products. The plots were covered with nonwovens directly after sowing and first fertilization (Figure 1B). After 41 and then after 132 days of sowing, the number of sprouting plants per 1 m^2 was counted (Figure 1C). Further analysis was not performed because the soil coverage with plants in the following growth seasons was sufficient to protect the soil from erosion and guaranteed proper vegetation reproduction of plants on the slope until full sodding.

Analyses of microbial population changes were performed at the beginning of experiment, then after 1.5 months, after 1 year, and after 2 years. On each occasion, soil samples were collected from the slope subsurface (5–15 cm below ground level). Next, a 5 g specimen (homogeneous, free of plant fragments) was mixed with 45 ml of sterile distilled water and then shaken in a laboratory shaker for 4h. Microorganism abundance was determined by a technique of plate cultures, applying successive serial dilutions of the soil-derived suspensions onto solid media (enriched agar, 2.5%, Biomaxima, for aerobic mesophilic bacteria, and Sabouraud medium with chloramphenicol, 6.5%, Biomaxima, for moulds and yeast). After 3–5 days of incubation, microbial colonies were counted and the microbial frequency was determined as the number of colony forming units (cfu) per 1 ml of original suspension and then per 1g of soil dry mass. At the same time, soil dry mass was assessed after drying of the soil sample to achieve constant weight at 105°C. The pH value of aqueous soil solutions was measured using an Elmetron pH-meter equipped with a CP-105 electrode.

All the plant analyses were carried out in at least three independent series of repetitions. Microorganism abundance determinations were performed in two replicates of soil extracts, each in at least three technical repetitions of suspension dilutions. The results were subjected to a statistical analysis using the ANOVA module of Statistica 13.5 (TIBCO Software Inc., Palo Alto, CA, USA). Statistical significance of differences was assessed using Tukey HSD test at an assumed probability level of $p < 0.05$.

RESULTS AND DISCUSSION

The first observations concerned the cover structures. The industrial-scale produced nonwoven fabrics 9 and 10 were fluffier, with more extensively ground and better fragmented feathers that were evenly distributed in the geotextile structure compared to nonwoven fabrics produced on a laboratory scale. These factors determined higher water holding capacity of these nonwovens and their easier overgrowth by plant seedlings, which is particularly important for clover.

Fig. 1. Experimental design: A) the slope before the start of the field test; B) construction of the experimental plots; C) turf formation one year after the start of the experiment (photo by P. Kacorzyk)

This early effect was noticeable upon the first assessment, i.e. after 42 days of sowing. At the time of the second analysis, i.e. after 132 days, decomposition process was observed for all the biodegradable nonwoven fabrics, and different size shreds were visible on the soil surface – the thinner nonwoven fabric was used, the smaller the shred size (Figure 2). At the same time, the control cover (no. 11) remained totally resistant to degradation, and had to be removed to provide proper growth of plants after the 132 days of the experiment.

During the first vegetation assessment carried out 42 days after the beginning of the experiment, it was found that the least number of grasses and clover had sprouted on plots A and B, i.e. those that were without cover (Table 3). The experimental variant A exhibited a total of 9 plants per m^2 while at the site B there were 18 sprouts. A significant increase in grass and clover abundance was recorded on the plot variants C, E, and M with an average of 70 plants. Variants D, H, and I were more intensely populated relative to C, E, and M, enabling growth of an average of 15 more plants. By far the largest plant number was observed for variants G, J, K, and L, where the average number of grasses reached 87. For variants K and L, the abundance of clover was the highest, reaching about 40 plants compared to the other tested combinations, in which the abundance of clover was statistically similar and ranged from 19 to 23 plants. During subsequent evaluation carried out in the middle of vegetation period, i.e. 132 days after sowing, an approximately 3-fold increase in grass abundance and a 2-fold increase in clover population were observed for objects without cover; however, these objects still had the lowest number of plants compared to the plots covered with the tested fabrics. On the test sites covered with nonwoven fabrics, the smallest increase of 8–9% in grass abundance was observed for variants F and H, while the greatest effect of a 69% increase was recorded for object L as compared to the first evaluation data. The respective values obtained for the other plots covered with the tested nonwovens ranged from 18 – 53%. After 132 days of sowing, the number of clover plants in variants K and L was the highest and amounted to 57 and 54, respectively, while on the other plots covered with nonwoven fabrics the counts ranged from 28 to 37 plants per 1 m^2. At this stage of the test, the highest total numbers of plants (grass + clover) were observed for objects K and L (nonwoven fabrics produced on the industrial scale) and reached 187 and 178 plants, respectively. Slightly lower plant number (156) was recorded at plot J, but the difference was not evaluated as statistically significant. The other variants covered with

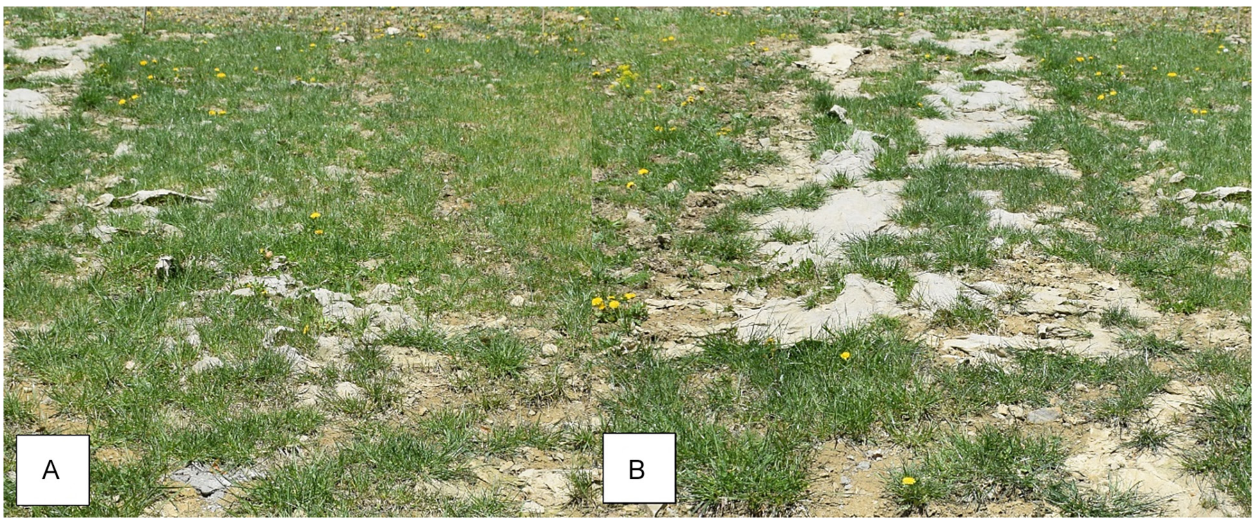

Fig. 2. Experimental plots at the second assessment (after 132 days of sowing); A: Variant H, Fabric no. 6, B: Variant G, Fabric no. 5 (photo by P. Kacorzyk)

Table 3. Number of sprouting plants per 1 m^2 of the plots determined during the field experiment (source: own elaboration)

Experimental variant	Days after sowing				
	41		132		
	Grasses	Clover	Grasses	Clover	Sum of plants
A	4 a	5 a	11 a	11 a	22 a
B	11 a	7 a	28 a	15 a	43 a
C	52 b	19 b	72 b	28 b	100 b
D	79 c	21 b	99 c	29 b	128 c
E	57 b	18 b	73 b	32 b	105 b
F	76 c	21 b	83 c	34 b	117 c
G	83 d	23 b	98 d	31 b	129 c
H	73 c	22 b	79 c	37 b	116 c
I	71 c	18 b	82 c	32 b	114 c
J	94 d	23 b	121 d	35 b	156 d
K	91 d	40 c	130 d	57 c	187 d
L	81 d	39 c	124 d	54 c	178 d
M	42 c	22 b	71 c	29 b	100 b

Values marked with the same letter are not significantly different at $p< 0.05$; statistical analysis was performed for each column separately. The totals of plants (grasses + clover) were not determined after the first stage of the field test (42 days).

nonwoven fabrics showed growth of plants within the range from 100 to 129 specimens. For the objects without cover (A and B), the total number of grass and clover were significantly the lowest at 22 and 43 plants, respectively.

It should be noted that biodegradable nonwoven fabrics are designed to support plant growth, especially in the early stages of development, when the risk of seeds, fertilizer and soil wash-out is the greatest. One year after the beginning of experiment for the variants covered with biodegradable geotextiles (i.e. variants C-L), turf formation was observed, which protected the soil from erosion. At the same time, well-developed root system of the plants provided water and nutrients for their further growth and development. These factors ensured proper sodding, so no further biometric analysis was conducted.

The initial development of plants on earth structures is determined by climatic conditions and by the soil substrate (Jeanbille et al., 2015). The nonwoven fabrics had a favourable effect on initial plant development. In general, the number of grasses per 1 m^2 tended to grow along with the increasing weight of the nonwoven fabrics. This relationship could not be transferred to clover seedlings, however. This discrepancy was most likely caused by the small percentage of clover seed in the applied mixture as well as by the seed size. Small clover seeds, with a higher mass density compared to grass seeds, most probably fell into the gaps between the soil aggregates at the time of sowing, and for that reason they were provided with better moisture conditions for growth and development in relation to grass seeds. The highest numbers of grass and clover seedlings, as determined for the sites K and L (covered with a low-weight nonwoven fabric nos. 9. and 10.), were enabled by the geotextile structure. The use of biodegradable nonwoven fabrics for covering earth structures reduces the risk of soil erosion, helps to eliminate an effect of washing away the seeds after sowing, and provides better conditions for seed germination and initial development of plants (Kacorzyk et al., 2018, 2021).

First analyses of the soil collected from the studied area revealed very poor microbial conditions, namely a relatively low occurrence of aerobic mesophilic bacteria amounting to $1.8 \cdot 10^5$ cfu · g^{-1} d.m. as well as poor yeast and moulds frequency determined as $4 \cdot 10^2$ cfu · g^{-1} d.m. Subsequent microbial analyses showed significant, at least 10-fold increase of microbiota population during the first stage of the field test (1.5 months). No statistical differences were observed between the controls (variants A and B) and the plot variants covered with nonwovens with regard to both bacterial (Figure 3) and fungal (Figure 4) population growth as determined after particular time intervals. However, it should be noted that while bacterial abundance, in general, remained stable, in the case of yeast and moulds their frequency tended to increase over the course of the experiment, for all the variants except for A, D and G, reaching the value of the order of 10^4 cfu/g soil d.m. after two years of study.

In the case of soil pH analyses, significant changes were observed, but they were associated with seasonal variations rather than with the use of nonwoven fabrics (Figure 5). No relationship was documented between the seasonal pH changes and microbiota abundance. Similar changes, yet not statistically significant, were observed regarding soil dry mass (Figure 6).

The soil organic layer plays a crucial role in the growth of microorganisms. Enriching the substrate with organic matter has a notable positive impact on microbiota population and their functional diversity. The prolonged use of poultry litter resulted in an improvement of soil properties and an increase in microbial community population (Dusa et al., 2022; Gupta et al., 2022). Bird feathers used as the components of biodegradable fabrics consist mainly of keratin. Although there exist some environmental microorganisms capable of using this protein as a source of carbon and energy for growth (Lange et al., 2016; Li, 2022), for most bacterial strains it is not the most important growth-stimulatory factor. In our study, the content

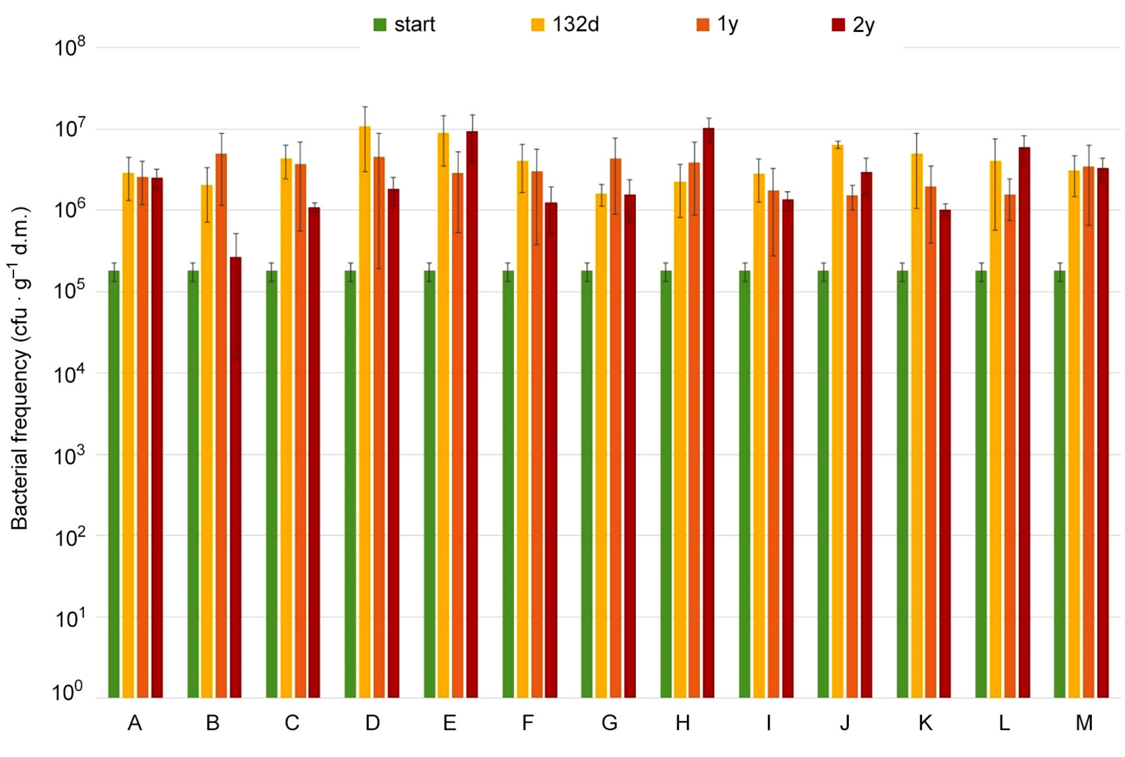

Fig. 3. Population changes of aerobic mesophilic bacteria in the soil during the experiment. For the description of the analysed variants A–M, see: Table 2 (source: own elaboration)

Fig. 4. Population changes of yeast and moulds in the soil during the experiment. For the description of the analysed variants A–M, see: Table 2 (source: own elaboration)

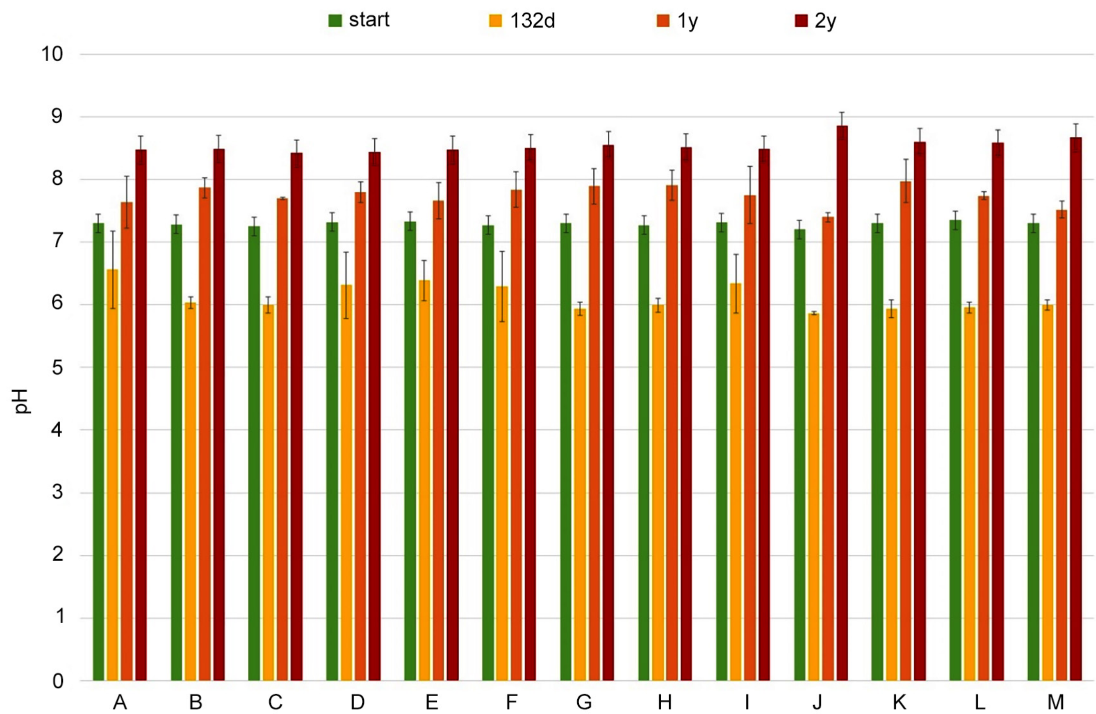

Fig. 5. Changes in soil pH during the experiment. A–M represent experimental variants as described in Table 2 (source: own elaboration)

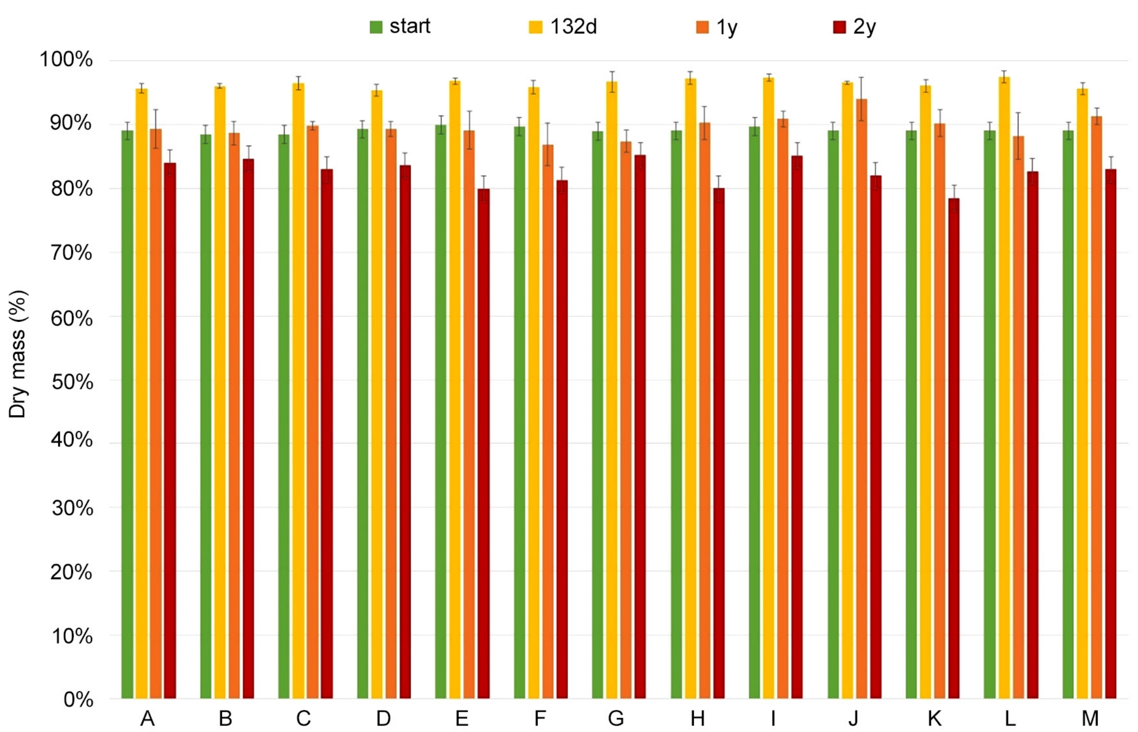

Fig. 6. Soil dry mass changes during the experiment. A–M represent experimental variants as described in Table 2 (source: own elaboration)

of bird feathers in the tested nonwoven fabrics was probably too small to have a measurable impact on microbial abundance. For that reason the use of biodegradable nonwovens did not statistically influence the changes in dynamics of the environmental microbiota.

Importantly, a significant increase in bacterial and fungal populations following germination of grass and clover seeds was noticed. The greatest number of bacteria in the soil is usually found in the root zone (Chen et al., 2019; Dong et al., 2019), where root secretions supply bacteria with the nutrients necessary for their growth and reproduction (Knights et al., 2021). Therefore, the applied biotextiles are expected to have an indirect beneficial effect on soil microorganisms that participate in promoting plant growth.

It is well known that soil pH strongly influences both the abundance and the species composition of microorganisms (Kim et al., 2016; Jiao and Lu, 2019; Shen et al., 2019). For neutrophilic bacteria – the most common bacteria in the environment – the optimum pH for reproduction ranges from 5 to 9 (Jin and Kirk, 2018). In our analyses, despite apparent fluctuations in pH from around 6 to almost 9, no pronounced effect of this factor on microbial growth was observed, which may be linked to protective effect of developing plants on microorganism population.

CONCLUSIONS

1. Covering with biodegradable nonwoven fabrics containing feathers, after the formation of earth structures and seed sowing to promote turf generation, has a beneficial effect on the initial development of the plants, sprouting stimulation, increasing the number of plants per 1 m^2 at least twofold compared with the control, non-covered fertilized sample, as well as reducing the risk of soil seeds washing out.
2. The grammage and texture of nonwoven fabrics affects plant germination and development. Nonwovens produced on laboratory scale with a grammage of 150–180 $g \cdot m^{-2}$ provide better conditions

for plant growth compared to control variants. However, the geotextiles with a lower grammage but fluffier structure, i.e. covers "Żagań I" and "Żagań II" produced on an industrial scale, bring the best results, making it easier for plants to grow through them. The ultimate count of plants observed for this two variants (187 and 178 per m^2, respectively) was over 4-times higher than for non-covered, fertilized control (43 plants per m^2) and almost two times higher than for the variant covered with control, commercially available film (100 plants per m^2).

3. Plant growth stimulation in plots covered with biodegradable geotextiles leads to the greater development of the plants, which, in turn, positively influences the abundance of soil microorganisms.

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ROLA WŁÓKNIN BIODEGRADOWALNYCH NA BUDOWLACH ZIEMNYCH PRZEZNACZONYCH DO ZADARNIENIA

ABSTRAKT

Cel pracy
Nowo utworzone struktury ziemne, takie jak stoki narciarskie, są obszarami trudnymi w zadarnianiu, ponieważ kolonizacja roślinami, ich początkowy rozwój i adaptacja są utrudnione z powodu niekorzystnych czynników klimatycznych i glebowych. Głównym celem badania było wykazanie możliwości zastosowania włóknin wykonanych z wełny owczej i odpadowych piór drobiowych na stokach górskich o dużym nachyleniu.

Materiał i metody
Biodegradowalne geowłókniny mogą być stosowane nie tylko do ochrony nasion i gleby przed wymywaniem, lecz także do promowania rozwoju darni i poprawy jakości mikrobiologicznej gleby. Podczas eksperymentu monitorowano wzrost roślin oraz zmianę liczebności drobnoustrojów.

Wyniki i wnioski
Wyniki świadczą o tym, że zastosowanie włókniny po wysianiu mieszanki traw i koniczyny miało wiele zalet, w tym przyspieszenie kiełkowania siewek, poprawę początkowego rozwoju roślin i zwiększenie liczby roślin na m^2. Ostateczny efekt biostymulacji był silnie uzależniony od biodegradowalności geowłókniny, a także jej gramatury i struktury. Najlepszą wydajność uzyskano przy gramaturze włókniny w zakresie 150–180 g na m^2. Promowanie wzrostu roślin, a w szczególności rozwój systemu korzeniowego, miało znaczący pozytywny wpływ na populację mikrobioty glebowej.

Słowa kluczowe: biodegradowalne włókniny, zbocza górskie, zadarnianie, mikrobiota glebowa