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The Impact of Biodegradable Geotextiles on the Effect of Sodding of Difficult Terrain

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Abstract: Difficult terrain is characterized by deteriorated conditions for plant adaptation, e.g., owing to poor substrate, substantial land slope, or intensive insolation. In terms of plant adaptation, difficult terrain includes newly created ski slopes, any kind of embankment, scarps, levees, and etc. Application of grasses is an effective and economic method of stabilization of the ground. However, sowing of grass-legume mixtures to sod these areas does not typically produce adequate effects. Application of a new generation of protective fabrics with the addition of bird feathers may be a remedy to these problems. The aim of this study was to evaluate the applicability of biodegradable fabrics for covering difficult areas to improve the habitat conditions for plants. To evaluate this issue, an area characterized by difficult conditions for plant development was selected. Five types of protective fabrics were applied. The main factor influencing the efficiency of the sodding of difficult terrain was the application of fabrics that were capable of absorbing water, which were then given to plants over a longer period of time. Vegetation grew easiest through the geotextile made of sheep wool with the addition of bird feathers. Fabrics manufactured from problematic waste materials contribute to an ecological effect as well as an economic effect resulting from lower costs of waste management as well as the income from selling the innovative product.

Keywords: biodegradable geotextiles; sodding; ecological effect; economic effect

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Citation: Kacorzyk, P.; Strojny, J.; Białczyk, B. The Impact of Biodegradable Geotextiles on the Effect of Sodding of Difficult Terrain. *Sustainability* **2021**, *13*, 5828. https://doi.org/10.3390/su13115828

Academic Editor: Damian Chmura

Received: 15 April 2021
Accepted: 17 May 2021
Published: 21 May 2021

1. Introduction

Difficult terrain includes areas on which plant adaptation is inhibited due to poor substrate, substantial land slope, and intensive insolation. In terms of plant adaptation, difficult terrain includes levees, newly created ski slopes, roadside drainage ditches, any kind of embankment, scarps, and etc.

Currently, there are over 8500 km of levees in Poland. More than 13% of them were built one hundred years ago, but there are also 500- and 700-year-old embankments [1]. Currently, no new embankments are being built, and only the already-existing ones are being repaired. Of these embankments, 12% are in good condition and do not threaten safety; the condition of 70% may pose a risk, whereas 18% pose a significant threat. When modernizing these areas, rapid sodding is of great importance because, when a flood wave hits, embankments are easily washed out. This involves renovation costs, but most significantly poses a threat to nearby citizens.

Montane areas make up almost 9% of the country's area [2]. According to GOPR (Polish Mountain Rescue Services) and TOPR (Tatra Volunteer Search and Rescue), there were 181 functioning ski lifts and approximately 255 km of downhill runs in Poland in 2014, and new ones are erected every year. In connection with the dynamic development of ski tourism, there is the demand for new pistes formed in a way that accommodates skiers' demands [3]. When trails are being built (formed), substantial amounts of soil are being moved by excavating the bedrock that is poor in nutrients and biological life, which are necessary for plant development. Additionally, this type of initial soil contains very little organic matter (which increases the soil's water capacity and improves the conditions for plant growth and development). Once the new piste has been properly formed, it is necessary to sod the area quickly to prevent soil erosion. Plant adaptation on a newly formed piste is difficult due to poor habitat conditions for plant development. Until now, municipal sewage sludge has been applied on formed pistes in order to improve soil trophicity. This is not a good solution, since sewage sludge is characterized by substantial variability of the chemical composition and contains detergent residues, which lead to pollution of runoff water and to a reduction of biological life in the soil [4]. The most dangerous toxic substances that are present in sewage sludge include heavy metals [5]. Moreover, the dark (black) color of sewage sludge causes it to heat up intensely on sunny days and then dry up very quickly. In this situation, plant seedlings die due to water shortages. Sewage sludge is characterized by substantial hydration, which causes high costs of transport and of use on pistes.

Another important difficult-to-develop terrain is the ditch, several of which occur along traffic routes and slopes created during the construction of roads in mountainous terrain. The Polish network of trunk highways is comprised of the most important trunk highways that handle international and interregional routes. According to the state at the end of 2018, public roads in Poland constituted about 420 thousand km, whereas trunk highways constituted over 19.3 thousand km. The phenomena of ground subsidence and surface erosion occur particularly after intensive rainfall on still surfaces without vegetation, thus initiating surface runoff and increased flows in road ditches. To protect the profiles of roadside ditches and slopes against erosion, reinforcements made of stones or paving stones are used. However, this manner of reinforcement reduces the biologically active surface (which is significantly important in current times, particularly in urban agglomerations). The decreasing plant diversity and, particularly, the amount and density of plant roots have a significant impact on the stability and firmness of soil aggregates [6].

In connection with modernization of levees, extensions of road infrastructure, and of drainage ditches with substantial embankment slopes that go along with them, and also with the dynamic development of ski tourism and the construction of pistes, there is an urgent need to develop effective methods to prevent soil erosion while preserving of the biologically active surface [1]. On difficult terrains, on account of the function they have, rapid sodding of these earthen structures may be the solution to the problem of soil subsidence. Grasses in a mixture with legumes play a special role here. Firm and well-rooted sod assists in the stabilization and protection of the land against erosion [7]. Application of grasses is an effective and economic method of stabilization in connection with year-round ground cover with substantial stability, and rich root systems that are distributed horizontally in the soil and are adapted to different physicochemical conditions of the soil [8,9]. The plant above-ground part also plays an important role in maintaining proper sodding, and thereby in soil stabilization. The yield of the above-ground biomass should not be high, because a high yield entails higher costs associated with mowing and removing it. Obtainment of dense, even, and durable sod requires sowing with adequate sowing material and maintenance measures [10,11]. When planning the sodding of difficult terrain, one should also take into account the effect of plants on the environment, landscape esthetics, safety, and the durability of a given earthen structure. Whenever possible, a grass-legume mixture should be used to achieve appropriate sodding, which protects the soil against erosion. The main plant species for the sodding of earthen structures include: red fescue (*Festuca rubra* L.), tall fescue (*Festuca arundinacea* Schreb.), common meadow grass (*Poa pratensis* L.), perennial ryegrass (*Lolium perenne* L.), common bird's-foot trefoil (*Lotus corniculatus* L.), and white clover (*Trifolium repens* L.) [12,13].

The sowing of grass-legume mixtures to sod these areas does not typically produce adequate effects since precipitation (especially intensive) washes out seeds and soil and transfers them to lower parts of the slope. On the other hand, attention should be drawn to the fact that, in the case of lack of precipitation, seed growth is also impossible. Additionally, low water capacity of the substrate and substantial hillside slope cause rapid drying out of the surface soil. It is particularly unfavorable in the first stage of plant development, as the root system is poorly developed and cannot use water or nutrients located in deeper layers of the substrate, which is why seedlings often die on hot days. In this situation, cultivation and sowing measures should be repeated. Sometimes such a situation occurs repeatedly, particularly when precipitation is erratically distributed

Economic and ecological effects of erosion processes on earthen structures are high. The cost of a grass-legume mixture per 1 ha ranges from 400 to 600 EUR. To this sum, one should add the cost of fertilizers, preparing the substrate, and seed sowing. The price of these measures is varied and depends on terrain conditions, mainly on land slope and on the height above sea level. Soil erosion is one the factors that degrades the environment. Its usual effects include permanent changes in the relief, soils, water regimes, natural vegetation, and technical facilities. Such changes lead to the lowering of the production potential of the land, and ecological and landscape values.

Application of protective fabrics immediately after the sowing of a grass-legume mixture to improve habitat conditions for developing seedlings may be a solution to the problems associated with achieving proper sodding in a short time on difficult terrain. A fabric should be biodegradable with the following performance characteristics: light color, surface mass of about 150–300 $g \cdot m^{-2}$, good adhesion properties, substantial water capacity, and appropriate structure. Such a fabric should protect seeds and soil against wash, reduce the force with which raindrops hit soil aggregates, and inhibit rainwater runoff. On shallow, rocky soils, which are most common on ski slopes, it is not possible to cover all sown seeds with soil. A heavy fabric will press the seeds to the soil, cover them, and improve the conditions for germination and seedling development. The properties of the fabric for retention of precipitation water and of water from dew formed during the night, and then its slow evaporation during the day, owing to the light color of the fabric—high albedo, are very important for young plants. The microclimate (with increased moisture) created under the cover will cause a reduction of the temperature amplitude between day and night in comparison with uncovered surfaces. The fabric will reduce losses of ammonium nitrogen escaping from the soil to the atmosphere, which will be also a source of fertilizer components during its biodegradation and will protect young seedlings against birds. Application of a biodegradable fabric will allow its rapid, inexpensive management at the site of its application, while also constituting the lowest environmental burden in the entire life cycle of product, which will have measurable economic and ecological effects particularly on areas protected by a Natura 2000 site.

Geotextiles, which include non-woven geotextile fabrics, are common in commerce. These are flat, permeable textile materials. They are obtained as a result of mechanical, thermal, or chemical transformations [14,15]. Individual methods and technologies of production of non-woven geotextile fabrics determine the prospective use of the product [16]. Apart from quite widely used synthetic fibers, biodegradable non-woven geotextile fabrics are used more and more often, mainly in agriculture and horticulture. Biodegradable polymers—polylactic acid (PLA) and polypropylene with a photodegradant (PP)—are used for their production. A study by Siwek et al. [17] indicated that application of these materials in cultivation technology yielded many positive effects. Researchers in Chile also showed a beneficial effect of biodegradable agrotextile on lettuce (*Lactuca sativa* L.) development. The study results show that soil mulching using agrotextile has a positive effect on soil fertility and optimizes the conditions for plant growth and development [18].

In connection with the adverse effect of synthetic geotextiles on the environment, a wide-ranging search for biodegradable materials for their production is pending. Feathers from poultry slaughterhouses are an innovative proposal within the scope of biodegradable raw materials. Apart from the environmental effect, this type of agrotextile may play a special role in the improvement of habitat conditions for plants in difficult terrain. Poultry feathers are an animal by-product generated during poultry slaughter. Each year, the poultry industry in Poland generates about 100 thousand tons of this waste. After the European Parliament and the Council (EC) introduced Regulation No 1069/2009 regarding the ban on the use of poultry feathers in feeding breeding animals, feathers became an inexpensive and widely available raw material. Bird feathers are made mainly of an insoluble protein called keratin, which is also called a natural polymer. Keratin has a strong resistance to the impact of physical, chemical, and biological factors, including proteolytic enzymes. Keratin's resilience stems from its structure, and particularly from the presence of disulfide bridges in its structure [19,20]. To be able to use agrotextiles made of feathers for covering difficult areas in order to improve their trophicity, keratinolytic microorganisms with the capacity to break down keratin are required. These organisms are the focus of many biotechnological and microbiological studies [21–23]. The soil environment is one of the natural habitats of these organisms. Microorganisms make use of keratin as a source of nitrogen and carbon and generate the so-called keratinolytic enzymes, which break down keratin protein. Bacteria of the genus Bacillus have the highest capacity in this regard [24,25].

The aim of this study was to evaluate the applicability of biodegradable fabrics for covering difficult areas to improve the habitat conditions for plants. Properties of the non-woven geotextile fabrics produced for the purpose of the experiment were compared with alternative products that are widely available in the market and widely used. Non-woven geotextile fabrics, termed as alternative products in the sodding process, fulfilled the condition of economic profitability.

2. Materials and Methods

2.1. Characteristics of the Study Area

To evaluate the applicability of fabrics for the improvement of habitat conditions for plants in a difficult area, one of the areas described in the introduction, characterized by the most difficult conditions (in the authors' opinion) for plant development, was selected. The study was carried out on the Jaworzyna Krynicka piste. In terms of geological formation, the Jaworzyna Krynicka range belongs to Magurska Nappe. It is the main tectonic unit of Western Carpathians, which was formed as a result of folding, and then the accumulation of sandstones, shales, or marly rocks. Jaworzyna Krynicka [1114 m.a.s.l.] is the highest peak of the Jaworzyna Range, one of four mountain ranges of Beskid Sądecki that forms the Carpathians. It is characterized by the presence of alternately arranged layers of sedimentary rocks, including sandstone banks and conglomerates [26].

2.2. Characteristics of the Study Site

The experiment was set up on a piste with a 26% slope in the south-eastern direction at the height of 817 m.a.s.l. in the year 2019. Accurate location of the experiment site was obtained based on longitude and latitude readings using GPS (N 49°41′48′′, E 20°91′35′′). The soil on which the experiment was set up contained 32% sand fraction, 50% particulate fraction, and 18% clay fraction. Based on the classification of particle size distribution of soils and mineral materials [27], it was loam. Soil samples were collected from the depth of 7 cm with the use of a soil sampler that allowed for the sampling of soil cores from a specified depth. Physical properties of the soil before setting up the experiment were as follows: pH in 1 mol·dm^{-3} KCl was 6.15, organic matter content was 11.5 g·kg^{-1} DM, total N content was 0.95 g·kg^{-1} DM, content of available forms of P, K and Mg were 4.20, 102.0, and 156.0 mg·kg^{-1} DM, respectively. The study area on which the experiment was set up was not sodded. It was created as a result of forming the piste with heavy construction equipment.

2.3. Characterization of the Experiment

An experiment consisting of five variants in three repetitions was set up. Each plot had the area of 18 m^2. Prior to sowing of the grass-legume mixture, cultivation measures consisting of soil scarification with a harrow pulled across the slope were performed to reduce the washout. Then, on 5 June 2019, the grass-legume mixture was sown manually and, due to difficult conditions, the sowing standard was increased by 300%. Composition of the mixture is presented in Table 1. In the spring of 2019 and that of 2020, mineral fertilization was applied in the following doses: nitrogen 40 kg·ha^{-1} in the form of ammonium nitrate (34% N), phosphorus 30 kg·ha^{-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).

Table 1. Composition of the grass-legume mixture.

Species/Variety	Share In			
	Mixture	Pure Sowing	Mixture	Mixture
	%	kg·ha^{-1}		kg·18 m^{-2}
Festuca rubra L. Reda C/11	30	90	27	0.049
Festuca pratensis L. Cykada C/1	5	120	6	0.011
Poa pratensis L. Struga B	30	60	18	0.032
Lolium perenne L. Solen C/1	20	90	18	0.032
Trifolium repens L. Haifa	15	60	9	0.016

Five types of protective fabrics were applied. One fabric (variant C) was produced from sheep wool with the addition of bird feathers (14.6%) with a basis weight of 100 g·m^{-2} and a stitching frequency of 30 Hz. This fabric was produced within the project "Elaboration of innovative protective fabrics with the addition of feathers". The project was co-financed by the European Regional Development Fund under Measure 4.1 of the Intelligent Development Operational Program 2014–2020. Three other fabrics—with symbol SB 9/14/1-5 and basis weight of 29.18 g·m^{-2} (variant D), with symbol SB 12/14/2 and basis weight of 77.32 g·m^{-2} (variant E), and with symbol SB 11/14/1 and basis weight of 96.62 g·m^{-2} (variant F)—were produced within the project BIOMASS (The Innovative Economy Operational Programme 01.01.02-10-123/09), co-financed by the European Union under the European Regional Development Fund. Important parameters of these fabrics include biodegradability and the water retention capacity. No additional information was provided to the authors of this study. Nevertheless, it was assumed that it was not essential in the context of this study. A commercially available fabric called Pegas Agro, with basis weight of 17 g·m^{-2} (variant G), was also applied.

The following seven variants, differing in the type of protective fabric used and in fertilization, were obtained:

Variant A: Control—grass-legume mixture
Variant B: Grass-legume mixture + fertilization
Variant C: Grass-legume mixture + fertilization + fabric made of wool and feathers
Variant D: Grass-legume mixture + fertilization + fabric SB 9/14/1-5
Variant E: Grass-legume mixture + fertilization + fabric SB 12/14/2
Variant F: Grass-legume mixture + fertilization + fabric SB 11/14/1
Variant G: Grass-legume mixture + fertilization + commercial fabric Pegas Agro wiosenna

2.4. Characterization of the Analytical Methods

In air-dry soil samples, granulometric composition was determined using the Casagrande's aerometric method modified by Prószyński [PN-R-04032]. Nitrogen content in the soil and in natural fertilizers was determined by the Kjeldahl method on a KjelFlex K-360 apparatus [28]. The content of available forms of phosphorus and potassium in the soil was determined by the Egner-Riehm method, and the content of available magnesium by the Schachtschabel method [28]. The soil pH in water suspension and in 1 mol·dm^{-3} KCl was determined by the potentiometric method [28].

The water capacity of the fabrics was determined under laboratory conditions. Fabric samples with the area of 1 m^2 after drying at 105 °C were weighed and then immersed in water for 0.5 h. After removal from water and draining of gravitational water for 0.5 h, the samples were weighed once again. Following that, the fabrics were spread on a laboratory table and weighed after 2 and 24 h, and the percent of water retained was computed from the obtained values.

The surface moisture content of the soil was measured using a ThetaProbe ML2x moisture probe (precision of measurement ± 1%). Measurements were carried out at soil depths between 1 and 6 cm. Sodding was computed by randomly applying a calibrated measure (100 cm) against the surface and, then, by adding the length of the sections covered with vegetation, the percent of its sodding was obtained.

All the analyses were carried out in at least three independent series of repetitions. The results were subjected to statistical analysis using the ANOVA module of Statistica 12.0 PL software. The significance of differences was assessed using Tukey's HSD test at an assumed probability level of $p = 0.05$.

3. Results

3.1. Solution Application Area

This solution is dedicated to all areas with substantial slope which are intended for sodding. Sodding of such areas is difficult owing to substantial slope, poor nutrients and biological life, and low water capacity. With respect to the substrate and functions connected with it, ski slopes constitute particular challenges in the process of sodding. Potential applications also include the sodding of slopes of transportation infrastructure and slopes adjacent to residential and public utility buildings as well as levees.

3.2. Water Capacity of the Geotextiles

Based on the conducted laboratory tests, fabric made of wool and feathers, which took in 450 $g \cdot m^{-2}$ water, had the highest water capacity (Table 2). Fabric SB 11/14/1 was second in terms of water retained (12% less) in relation to the fabric made of wool and feathers. Fabric SB 12/14/2 ranked third, with 31% less water retained compared with the fabric made of wool and feathers. Fabric SB 9/14/1-5 and the commercial fabric retained 115 and 70 $g \cdot m^{-2}$, respectively, and these values were 74% and 75% lower than the best result, respectively. After two hours of drying, the two fabrics with the highest water capacity still had the highest content of water (between 61% and 63%) in relation to the initial state. Fabrics SB 9/14/1-5 and SB 12/14/2, subjected to two-hour drying, retained 33% and 54% water, respectively. Commercial fabric, after the two-hour drying period, dehydrated the fastest. It contained only 10% water. After 24 h of drying, the fabric made of wool and feathers, as well as fabric SB 11/14/1, still contained almost 11% water. Other fabrics contained 8% water each.

Table 2. Water capacity of fabrics and their water retention capacity.

Type of Fabric	Basis Weight of Fabrics	Amount of Water Retained	Amount of Water Retained	
			After 2 h of Drying	After 24 h of Drying
	$g \cdot m^{-2}$		%	
Wool + feathers	100.00	450 d	61.33 c	10.67 b
SB 9/14/1-5	29.18	115 b	32.56 b	8.03 a
SB 12/14/2	77.32	309 c	54.37 c	8.01 a
SB 11/14/1	96.62	396 d	62.63 c	10.81 b
Pegas Agro	17.82	70 a	10.04 a	8.04 a

Values marked with the same symbol in columns do not differ significantly at $p = 0.05$ (based on ANOVA results and Tukey test). a,b,c,d–designator of homogeneous groups membership (based on Tukey test results).

3.3. Soil Moisture Content

After application of fabrics under field conditions, the soil moisture content in all plots was measured. On average, plots A and B without fabrics were characterized by the lowest soil humidity (26%) (Table 3). The soil moisture content in variant G, covered with commercial fabric, was 30.5% and was higher by 17 percent points than the soil moisture content measured in plot A. Variant D, covered with fabric SB 9/14/1-5, was next in line in terms of soil moisture content (with the result of 33.1%). In other variants, the soil moisture content ranged from 35.2% to 37.0%; the difference between them was statistically insignificant. The difference between variant A without cover (with the lowest soil moisture content) and variant C covered with fabric made of wool and feathers (with the highest moisture content) was 42 percent points.

Table 3. Percent of moisture in a 1 to 6 cm soil layer.

Variant	Percent Moisture of the Soil Surface Layer				
	Year 2019			Year 2020	Mean
	July	August	October	July	
A—Control	12.6	18.1	43.4	30.6	26.2 a
B—Variant	11.8	17.3	44.0	32.3	26.3 a
C—Wool + feathers	20.0	23.7	54.9	49.6	37.0 c
D—SB 9/14/1-5	16.3	19.4	54.2	42.4	33.1 b
E—SB 12/14/2	18.8	20.3	55.7	45.8	35.2 c
F—SB 11/14/1	19.2	21.8	58.7	45.3	36.2 c
G—Pegas Agro	13.9	19.2	51.4	37.4	30.5 b

Values marked with the same symbol in columns do not differ significantly at $p = 0.05$ (based on ANOVA results and Tukey test). a,b,c,d—designator of homogeneous groups membership (based on Tukey test results).

3.4. Soil Sodding Assesment

The first assessment of soil sodding was conducted at the beginning of July 2019. In variants A and B without cover, soil sodding was 15.2% and 18.3%, respectively (Table 4). In the above-mentioned plots, ungerminated seeds were visible on the soil surface (Figures 1 and 2). Variants C, D, F, and G, covered with fabrics produced within the framework of the project, had soil coverage between 62.3% and 71.0%. On average, sodding in these plots was over four times better than in plots not covered. Sodding of the plot covered with commercial fabric was 42.5%. In plots C and D, vegetation grew through the fabrics (Figures 3 and 4). Vegetation in variant E grew through fabric SB 12/14/2 with difficulty (Figure 5). In plot F with fabric SB 11/14/1, plants grew through the fabric only in 40% of cases; the remaining plants grew under the fabric, thus raising it (Figure 6). Vegetation in variant G, covered with commercial fabric, did not grow through it (Figure 6). In these last two variants, fabrics were removed during the first assessment. In other variants, fabrics were not removed (they had been biodegraded). The percent of soil sodding increased with the passage of time in all variants, but the increase in vegetation was varied. In July 2020, the best sodding was observed in variants C and D (reaching 100%); about 5% poorer sodding was observed in variants E and F. The next position belonged to the variant covered with commercial fabric; its sodding reached 85.1%. Sodding in variant B was at the level of 68.3%. The poorest sodding was observed in variant A (only 45.8%).

Table 4. Percent of soil sodding on four study dates.

Variant	Percent of Soil Sodding			
	Year 2019			Year 2020
	July	August	October	July
A—Control	15.2 a	26.3 a	36.8 a	45.8 a
B—Variant	18.3 a	38.4 b	42.0 a	68.3 b
C—Wool + feathers	70.6 c	79.9 d	92.3 d	100.0 d
D—SB 9/14/1-5	68.6 c	80.5 d	94.8 d	100.0 d
E—SB 12/14/2	62.3 c	77.7 d	88.3 c	95.6 d
F—SB 11/14/1	71.0 c	78.8 d	83.2 c	94.8 d
G—Pegas Agro	42.5 b	57.8 c	73.4 b	85.1 c

Values marked with the same symbol do not differ significantly at $p = 0.05$ (based on ANOVA results and Tukey test). a,b,c,d–designator of homogeneous groups membership (based on Tukey test results).

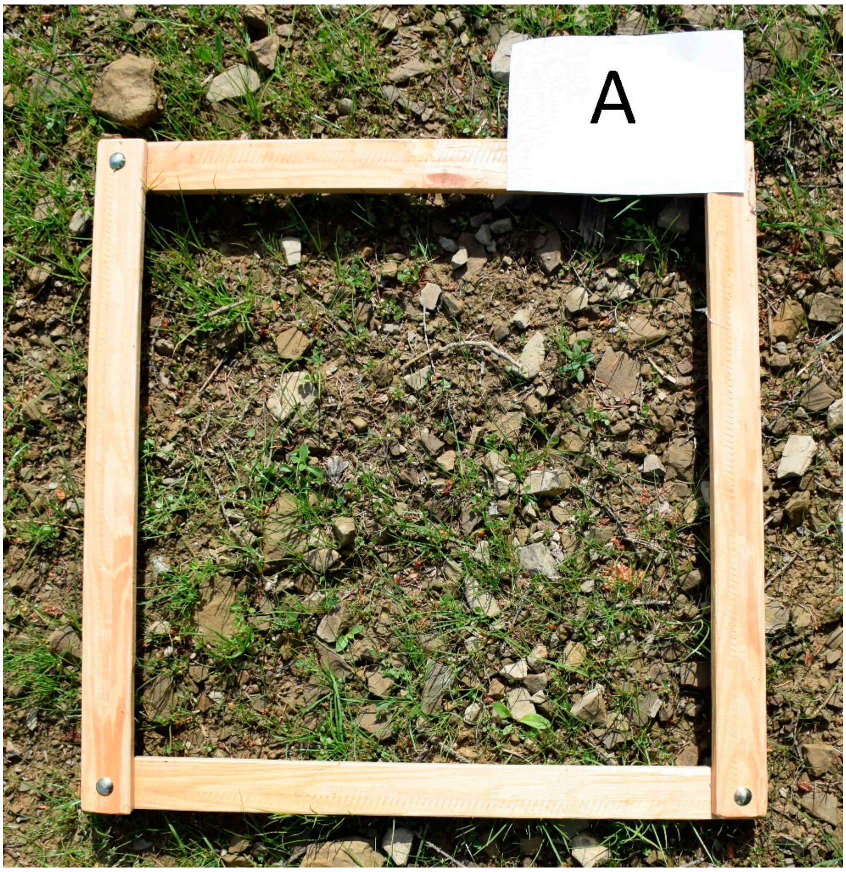

Figure 1. Sodding of variant A: control—grass-legume mixture.

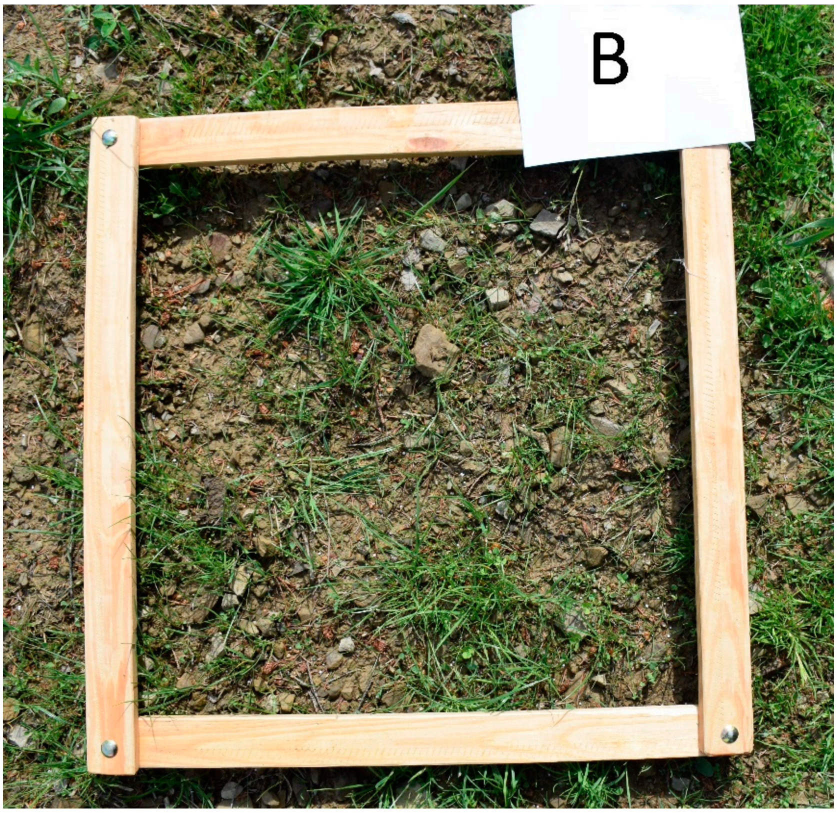

Figure 2. Sodding of variant B: grass-legume mixture and fertilization.

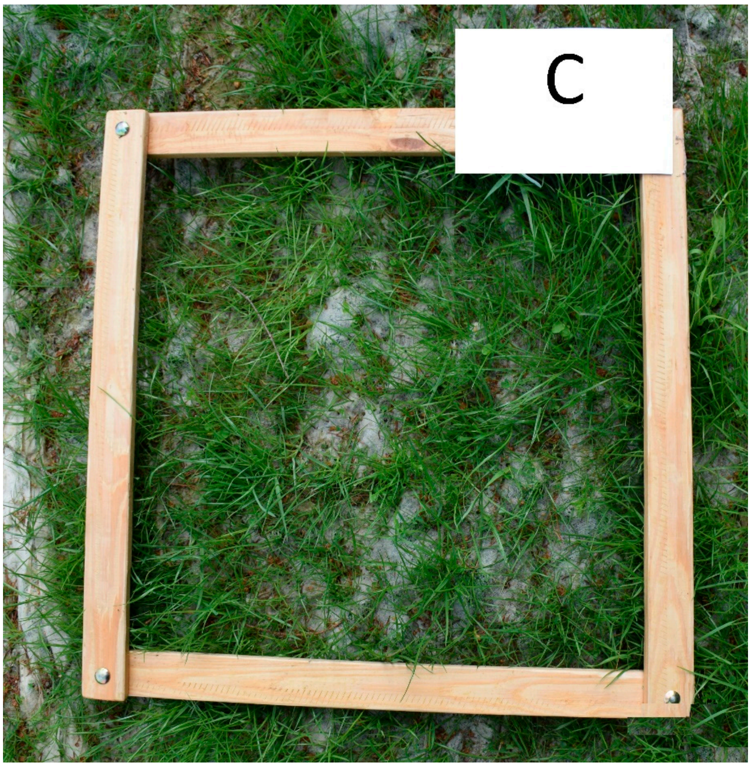

Figure 3. Sodding of variant C: grass-legume mixture, fertilization, and fabric made of wool and feathers.

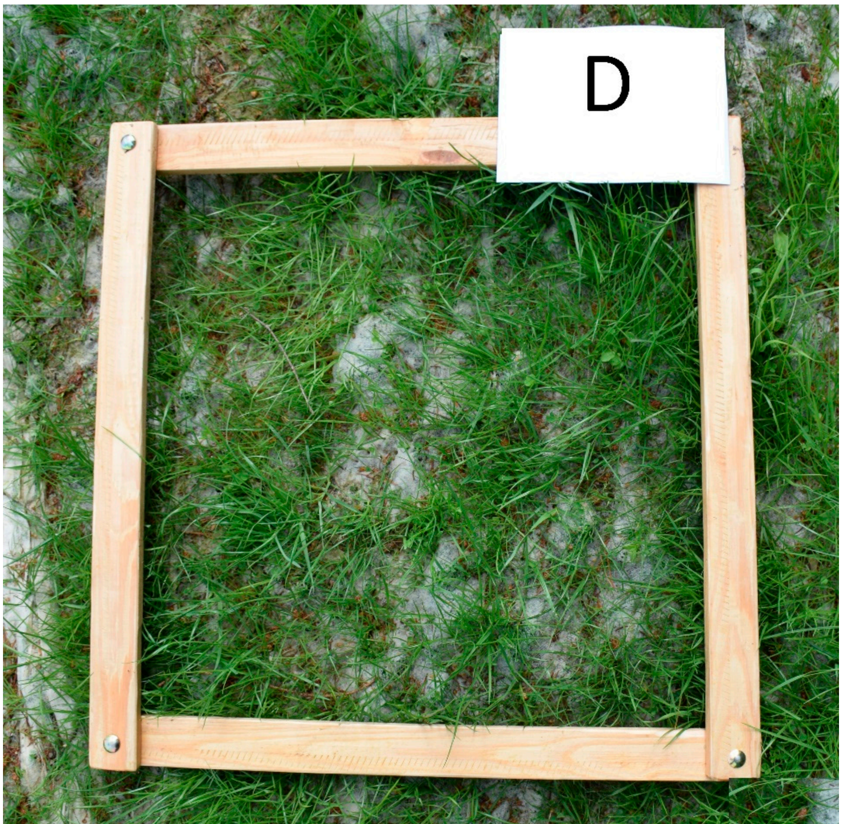

Figure 4. Sodding of variant D: grass-legume mixture, fertilization, and fabric SB 9/14/1-5.

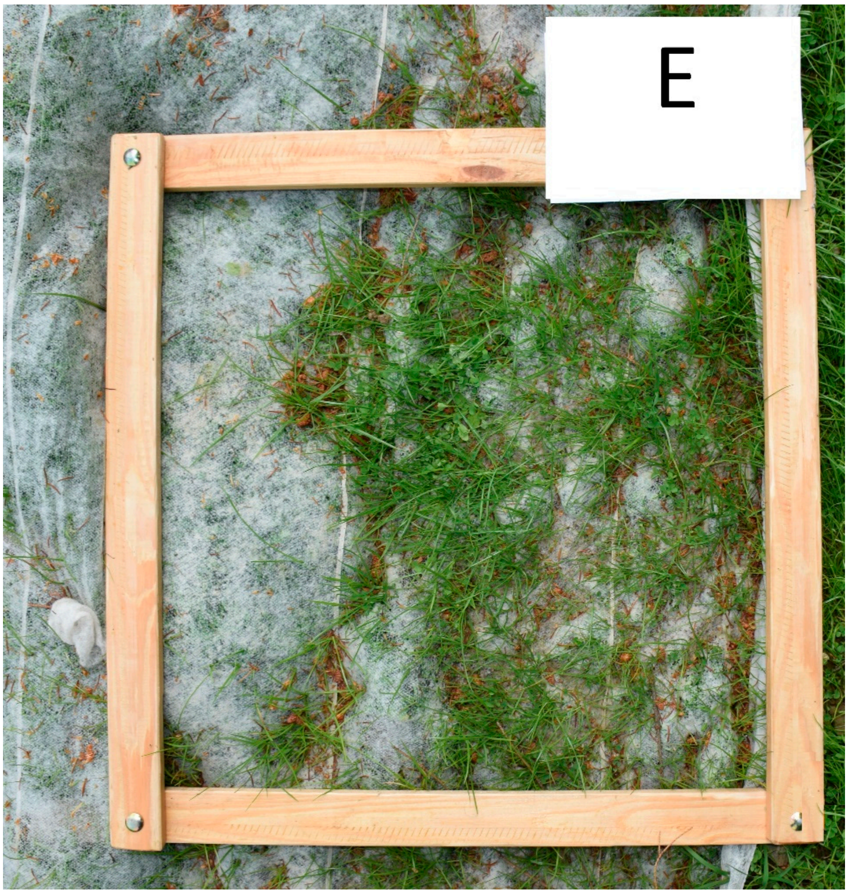

Figure 5. Sodding of variant E: grass-legume mixture, fertilization, and fabric SB 12/14/2.

Figure 6. Sodding of variant F: grass-legume mixture, fertilization, and fabric SB 11/14/1; variant G: grass-legume mixture, fertilization, and Pegas Agro commercial spring protection fabric.

4. Discussion

Placing a lawn in rolls is a common practice for rapid sodding of areas. The most difficult areas to set up a lawn in a roll on include surfaces with considerable slopes or with difficult conditions for plant life (e.g., car parks and median strips along highways). Sodding and strengthening of these types of surfaces is extremely problematic with respect to hindered access. The most important goal in setting up lawns in such areas is usually the protection against erosion. Additionally, a lawn raises the aesthetic quality of a site. However, Bache and MacAskill [29] remarked that the use of turf is limited by economic and practical considerations. On steep slopes, it may be necessary to protect the sod against sliding. Apart from the technical problems and the costs of laying sod from rolls, it may not have appropriate species composition. In addition, covering large areas may turn out to be impossible on account of the limited availability of sod.

Under standard conditions, agricultural practices consist of putting seeds into soil which is subsequently consolidated. These well-established sowing techniques cannot be applied in difficult terrain [30–32]. The technique that enables the circumvention of some of the problems occurring on steep slopes, in particular to set the initial establishment, is hydroseeding or hydromulching. This method consists of distributing the seeds and nutrients as a slurry over the terrain. Technically, the water mixture containing selected seeds can be sprayed in difficult terrain. The properties and composition of a mixture containing seeds may be composed adequately for specific habitat conditions [33–36].

Proper consistency of the mixture may be secured by adding an adhesive agent such as starch derivatives or emulsions. These additions compose a more viscous mixture which enhances the adherence of the mixture to the ground. Additions can also play the role of bean stabilizers. To secure seed germination and seedling growth, high bulk materials such as wood-pulp, straw, or peat can be added. These substances protect germs against drying and reduce the translocation of seeds. Improper soil acidity as well as potential deficiencies of nutrients are corrected by adding nutrients. Mineral fertilizers can be added at later stages of vegetation. Bradshaw and Chadwick [37] noticed that, in some cases, omitting fertilizers in a mixture with seeds accelerated germination.

The indicated problems with the sowing of grasses in difficult terrain can be effectively solved by applying permeable geotextiles. This category includes woven geotextile fabrics, non-woven geotextile fabrics, and knitted geotextile fabrics [38,39]. Geotextiles are widely used in contact with soil and other materials in geotechnical engineering [40,41]. When used in geotechnical applications, geotextiles tend to perform a few functions at the same time. The main functions of geotextiles in geotechnical engineering can be listed as [42]:

- Separation and barrier [43].
- Reinforcement (geotextiles used as reinforcing materials to form a reinforced soil) and erosion protection. Mechanical properties of geotextiles are crucial in these applications [44].
- Drainage [45].
- Filtration and the role of soil conservation or stabilization [46,47].

As a result of technological progress in the field of fiber materials, new types of geotextiles are created, e.g., wicking geotextiles that can drain both gravitational and capillary water [48,49]. Different types of additives are used to enhance the performance of geotextiles [50].

Geotextiles are of ever-growing importance particularly in geotechnical engineering, but also in environmental protection. Geotextiles are considered as easy-to-use, durable, and cost-effective technologies. The selection of the geotextile type should mainly accommodate the performance requirements of the application. The factors that determine the choice of the geotextile undoubtedly also include the production costs. Additionally, the assessment of an engineering project should account for environmental costs [51]. At present, the basic materials used for geotextile manufacturing are predominantly synthetic fibers.

The most widely used fiber in geotextiles is polypropylene (PP) due to its tensile strength, low density, and low cost of production. On the other hand, polypropylene is characterized by poor sensitivity to UV light [52] and poor creep characteristics at high temperatures [53]. Polyethylene terephthalate (PET), which is another major synthetic fiber used for geotextile manufacturing, is distinguished by high creep resistance (even at high temperatures) and excellent tensile properties. The main disadvantage of this fabric is that it degrades easily in soil with a high pH value [54]. Polyethylene (PE) and polyamide are relatively rarely used as raw materials for geotextile manufacturing. In particular, polyamide is characterized by poor comprehensive performance [41]. An overview of the properties of geosynthetic liner materials used in environmental applications was presented by Touze-Foltza et al. [55].

Wu et al. indicated that [56] 1.4 billion square meters of geotextiles are used annually. In 2019, the global geotextile market size was estimated to be 4.6 billion US dollars, and the trend is on the rise. The compound annual growth rate is expected to be about 12%. The main fields of application of geotextiles include road construction (47%), erosion prevention (20%), and drainage systems (17%). The two most important trends regarding geotextiles that can be currently observed are their increasingly common use in geotechnical engineering as well as innovative processes with respect to materials, and, as a result, a widening range of applications. A special type of innovation is the creation of so-called 'intelligent geotextiles', which consists of applying advanced sensing technologies such as fiber optics, photogrammetry, and other sensing techniques into geotextiles [57–59]. These solutions enable the monitoring of structural health and the assessment of the infrastructure performance. Another direction of innovation, resulting from the expansion of the application of geotextiles, is the development of high-performance geotextiles. It lends itself to the creation of multi-functional, high-strength materials that meet the complexity requirements of the environment. The main means employed to improve the performance of geotextiles are composite geotextiles, chemical modification, and additives [60].

Most geotextiles used both in geotechnical engineering and in other applications are made of non-degradable polymers (about 98%). In the long run, such a wide use of geotextiles may lead to environmental damage [61]. As a result of a long-term use in external environmental conditions, the disintegration of the polymers will cause pollution of the environment [62,63]. Additionally, the breakdown of synthetic polymers may result in the accumulation of microplastics in the environment [64–66].

Due to the restrictive qualitative requirements of geofabrics and their potential burden on the environment caused by the products of breakdown of synthetic materials, there is a wide-ranging search aimed at replacing non-biodegradable polymer geotextiles with natural geotextiles [67]. Some authors suggest that there is a possibility to replace synthetic geotextiles with natural geotextiles, even in the case of 50% of applications [68]. Recently, there has been a rising trend in innovation in the field of natural fibers. Many efforts have been made to improve the performance of natural fibers to extend their applications. Natural fiber composites have a low environmental impact due to their biodegradability. This attribute supports the potential of natural geotextiles across a wide range of applications [69–72].

Overall, there are three kinds of natural fibers used for geotextile manufacturing: mineral fibers, animal fibers, and plant fibers [73]. The major structural component of plant fibers is cellulose, whereas animal fibers, for the most part, consist of protein. Among natural geotextiles, fabrics based on plant fibers have become most common because of low cost, ease of sourcing, abundance of related resources, and also due to good mechanical properties, which result in superior performance [74–76]. High-performance plant fibers generally provide much higher stiffnesses and strengths than the easily available animal fibers. The characteristics of natural fibers vary considerably and relate to fiber type, extraction method, and treatment [77]. On the whole, higher performance is achieved with plants that have a higher cellulose content [78]. In recent decades, much progress has occurred in the mechanical performance of natural fiber composites due to improved fiber selection, treatment, and composite processing. Mineral-based fibers that exist within the asbestos group of minerals are presently avoided due to associated health issues.

Owing to slow biodegradation, natural geotextiles maintain their protective potential long enough to ensure the development of protective vegetation on the slope [79]. Geotextiles based on natural materials which were subjected (during the production process) to various processes aimed at increasing their strength and longevity had the capacity to enhance their long-term tensile strength and water repellence [80]. These materials' improvements may make natural geotextiles useful in the processes of vegetation growth, temporary reinforcement of the ground, and other processes that strengthen the soil.

The importance of a fabric in areas difficult to sod is of different character in relation to its properties used in geotechnical engineering or in pomiculture or horticulture. The main threats to the initial plant development in difficult terrain are quick runoff of precipitation water, soil erosion, seed washout, soil impoverishment in nutrients, and excessive exposition to sunrays. Therefore, covering difficult terrain with fabric provides a significant advantage to seedlings in the face of unfavorable habitat conditions. Since fabric slows down the fall of raindrops onto soil aggregates, absorbs water, limits surface runoff, reduces nutrient losses from the soil, and is a source of moisture on rainless days, it creates favorable conditions for plant development [81]. Moreover, white fabric increases the albedo of covered areas. The albedo of a white surface is comparable to the albedo of fresh snow [82]. It is extremely beneficial for plants under it, because they are not in danger of direct exposure to sunrays.

This study indicated that the basis weight of a fabric is positively correlated with the quantity of water retained and negatively correlated with the quantity of water evaporated. The type of raw material used for the manufacture of fibers also has an impact on the amount of water retained and evaporated in a unit of time. The investigated fabrics, which contained 8% water after 24 h, can be regarded as air-dry. Fabrics applied in variants C, D, E, and F clearly improved the soil moisture conditions. The commercial fabric (variant G) had the lowest basis weight, weakly pressed the seeds against the soil, and absorbed less water with respect to other fabrics. However, the soil moisture content and sodding were much better than in the variants without fabrics. The parameter of growing through the fabric is associated with the basis weight; it can be surmised that, with an increase in basis weight, the overgrowing capacity of plants will deteriorate. This relationship was confirmed with respect to the fabrics tested in this study (manufactured within the project "BIOMASA"). Of the fibers used in the experiment, plants grew through the fabric made of wool and feathers with greatest ease, despite it having the greatest basis weight. This ease with which plants grew through the fabric made of wool and feathers resulted from its fluffy structure, which also influenced the water capacity and absorption of water from steam. Commercial fabrics are obtained as a result of mechanical transformations such as stitching, or thermal transformations such as welding. This is why fibers are permanently interconnected, preventing plant overgrowth.

In accordance with the results of empirical research, using natural fabrics for sodding of difficult terrain yields desired technological effects, and it is also economically efficient and environmentally-friendly [83]. The study by Siwek et al. [84] supported the conclusion that biodegradable fabrics are a suitable alternative to synthetic fabrics. Geotextiles based on natural materials have the potential to replace synthetic geotextiles for a wide range of applications [68]. Geotextiles made of natural fibers generally have low cost, are suitable for a wide range of applications, and are biodegradable [85]. This study proved that sodding of difficult terrain with the use of biodegradable fabrics was characterized by a more intense plant growth compared with the control (variants A, B—without the technology of introducing plant protection and of assisting plant growth).

5. Conclusions

1. Based on the study, it was determined that rapid and permanent sodding of difficult terrain is possible provided that agents assisting in the initial development of plants are applied.

2. The main factor influencing the efficiency of sodding of difficult terrain is the application of fabrics that are capable of absorbing up to 45.0% of water from precipitation and from steam, which are then given to plants over a longer period of time, thus stabilizing the water regime.
3. Considering fabrics used in the experiment, vegetation grew easiest through the geotextile made of sheep wool with the addition of bird feathers, despite it having the greatest basis weight. The ease with which plants grew through the geotextile made of wool and feathers resulted from its fluffy structure, which also affected the water capacity and absorption of water from steam.
4. Using problematic waste (bird feathers from poultry slaughterhouse) for the manufacture of fabrics has a number of advantages: one can obtain a fluffy fabric with adequate parameters for the sodding of difficult terrain, fabrics are biodegraded at the site of application, and decomposing fabrics enrich the soil with nutrients for plants and are an alternative for synthetic fabrics.
5. Fabrics manufactured from problematic waste materials (bird feathers) contribute to a measurable ecological effect as well as an economic effect, which is a result of not having to bear the costs of waste management as well as the income from selling the innovative product.

6. Patents

Application No. P.430284—patent application for an invention at the Patent Office of the Republic of Poland, entitled "Method for producing fluffy composite nonwoven fabric", Warsaw, 19 June 2019.

Author Contributions: Conceptualization, P.K. and J.S.; methodology, P.K.; software, J.S.; validation, J.S. and B.B.; formal analysis, P.K., B.B., and J.S.; investigation, P.K. and B.B.; data curation, J.S.; writing—original draft preparation, P.K. and J.S.; writing—review and editing, P.K., B.B. and J.S.; visualization, J.S. and B.B.; supervision, P.K. and J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was carried out as part of the research project "Development of innovative protective nonwovens with addition of feathers". POIR.04.01.04-00-0059/17, co-financed by the EU. The research project was implemented as part of the National Center for Research and Development competition.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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