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The influence of non-woven fabric on the initial development of plants growing on difficult-to-sod river embankment surfaces

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Abstract: The aim of the study was to improve the habitat conditions in the initial development of a grass-legume mixture sown in the reconstructed river embankments along the Uszwica River in Kwików and the Vistula River in Kraków, Poland. For this purpose, after sowing the seeds, NPK fertilisation was used, along with the application of a hydrogel to limit the evaporation of water from the soil. Additionally, a non-woven fabric was used to cover the soil. The study was conducted in two stages. In the first stage, polymeric and five biodegradable non-woven fabrics were evaluated in laboratory conditions for their water absorption and retention capabilities. After this assessment, two biodegradable and one polymeric non-woven fabrics were selected for the second stage of field research. A grass-legume mixture consisting of five species of seeds: *Lolium perenne* L., *Poa pratensis* L., *Festuca rubra* L., *Festuca arundinacea* Schreb. and *Trifolium repens* L. was used for sowing the embankments. This study takes into account the concept of green economy aimed at addressing the challenges of securing difficult terrains, such as river embankments. The non-woven fabrics used to cover the soil had a positive effect on the initial development of plants, accelerating their emergence, and the degree of soil coverage. After two months post-sowing, the soil surface coverage under the non-woven fabrics was 50% higher compared to areas without such coverage. However, the type of non-woven fabrics and the hydrogel used did not have a significant impact on the initial development of seedlings.

Keywords: green economy, hydrogel, mineral fertilisation, non-woven fabric, river embankments, seed germination

INTRODUCTION

Earthen structures occupy a significant area in industrialised countries and are classified as difficult terrain. Among the most important structures of this type are river embankments, transportation routes, and ski runs. Currently, Poland has approximately 8500 km of embankments, which are managed by provincial land melioration and water unit boards. The main function of these embankments is to withstand water pressure during periods of high water for several days, protecting an area of about 1.1 million hectares. Notably, around 40% of embankments require reconstruction (Borys, 2007; Kołodziejczyk and Żebrowska, 2013). As of the end of 2022, the total length of urban and rural public roads was 427,580 km, of which hard surface public roads accounted for 317,529 km (GUS, 2024). According to the Mountain Volunteer Search and Rescue (Pol. Górskie Ochotnicze Pogotowie Ratunkowe – GOPR) and Tatra Volunteer Search and Rescue (Pol. Tatrzańskie Ochotnicze Pogotowie Ratunkowe – TOPR) data, there are 181 ski lifts in Poland, with ski runs totalling 255 km (personal information). The elements of the transport system are scattered over the landscape with some regularity. Along traffic routes, which are usually linear, various earthen and engineering structures, along with building and equipment complexes, are established. The size of structures depend much on the terrain (Wolak, 2018). Earthen structures are affected by often ignored cyclical factors. These variable factors include temperature and groundwater level. The temperature changes over time and with seasons (Bąk, 2015).

The area of embankments under management is 5–20 times greater than their length. A significant part of these surfaces is characterised by a large inclination and water erosion. Therefore, it is essential to cover these areas with permanent sodding, which helps reduce soil washout. Well rooted grass sod strengthens the slopes, contributes to their stability, durability of buildings, and prevents water erosion (Wysocka *et al.*, 2004; Kacorzyk *et al.*, 2013). To protect against erosion, especially on roadside slopes, reinforcements made of stones or paving bricks are used. However, this solution is significantly more expensive than sodding and at the same time limit the biologically active surface area, increase the proportion of hardened surfaces, and worsens the aesthetics of the landscape. Therefore, the selection of appropriate plant species plays an important role in maintaining proper sodding. Some basic species used for sodding on earthen structures include: *Poa pratensis* L., *Festuca rubra* L., *Lolium perenne* L. and *Trifolium repens* L. (Herbich, 2000; Dembek *et al.*, 2005; Zielewicz and Kozłowski, 2006; Kacorzyk and Kasperczyk, 2016). In addition to providing good sodding, these species yield a minimal amount of aboveground biomass, which significantly reduces the cost of mowing and removing the biomass (Koda, Osiński and Głażewski, 2010; Kacorzyk and Kasperczyk, 2016). However, sowing these plant species for sodding often does not yield satisfactory results. After heavy precipitation, the sown seeds are washed away with the topsoil, and the absence of rainfall can lead to reduced or even non-existent plan emergence due to severe soil drying. Under these conditions, cultivation procedures and sowing of seeds often need to be repeated. To reduce the negative effects of weather conditions, such as humidity and temperature fluctuations, as well as washout of seeds, non-woven fabrics are used to cover the soil after sowing. In addition, covering the sown surface with biodegradable non-woven fabrics, which were produced using agricultural bio-waste, contributes to better plant development, which creates denser and more compact turf (Vilchez *et al.*, 2020; Kacorzyk *et al.*, 2023). Moreover, biodegradable nonwoven fabrics promote the growth of microorganisms and improve plant-microorganism interactions, which stimulates plant growth by accelerating nutrient cycling in the ecosystem and plant resistance to stress factors (Meena *et al.*, 2020; Li, 2022; Mahatma *et al.*, 2023).

The density and quality of vegetation growing on flood embankments is of great importance for their function. Grasses play the most important role because they ensure the density and good rooting of the turf. This stabilises and protects the slope against water erosion (Chmura, Piotrowski and Wolski, 2006). Restoring vegetation by seeding is the best way to achieve biodiversity under these conditions (Freitag *et al.*, 2021). Maintaining or restoring turfed areas degraded by various factors and loss of biodiversity can be achieved by using various sowing methods, e.g. seeds or hay collected from areas with rich biodiversity, as well as seed mixtures specially composed for this purpose (Slodowicz *et al.*, 2023).

The soil moisture level can be improved by mixing the soil with hydrogel (Lentz, Sojka and Mackey, 2002; Śpitalniak, 2016; Księżak, 2018; Śpitalniak *et al.*, 2019). Hydrogels are classified as soil conditioners which help improve physical and chemical properties of soil. Hydrogels are often used to improve the moisture retention capacity of soil to enhance the plant productivity by maintaining relevant amount of water and nutrients available to plants, especially during water stress. Hydrogel can absorb about 300–500 times more water than the plant dry mass and gradually release it into the soil. Additionally, hydrogels increase water infiltration, reduce water loss through evaporation from the soil, compaction of soil and soil erosion as a result of surface run-off (Jinger, Sharma and Tomar, 2017; Paswan, Prajapati and Dholakiya, 2022; Wu, Li and Chen, 2023; Piccoli *et al.*, 2024).

The main goal of the study was to assess the possibility of using biodegradable non-woven fabrics and hydrogel to improve habitat conditions in the initial period of the sown mixture growth on two embankments. This study considered the concept of green economy used to resolve the issue of securing difficult terrain, including river embankments.

MATERIALS AND METHODS

LABORATORY TESTS

Before starting the field experiments, we evaluated non-woven fabrics as materials supporting the adaptation of plants in difficult areas such as river embankments. In laboratory conditions, we evaluated seven types of non-woven fabrics, including two commercially available synthetic non-woven fabrics, summer "S" and winter "W": Commercial "S", Commercial "W", and five biodegradable non-woven fabrics: SB 17/12/2, SB 38/12, SB 43/12/7, SB 43/12/5, SB 43/12/4. The biodegradable non-woven fabrics were produced based on rapeseed oil. The evaluation covered the following parameters: basis weight, water absorption and evaporation rate, water vapour permeability, and the emergence of seeds of *Lolium multiflorum* L. covered with non-woven fabrics. The manufacturer did not disclose other parameters of the non-woven fabrics and their manufacturing method to the authors of the study. However, it was established that these parameters were not crucial for the conducted study. The basis weight was determined by weighing non-woven fabrics of 1.0 m^2, and other laboratory tests were carried out on non-woven fabrics of 0.25 m^2 (50 × 50 cm). The water capacity was determined to reflect natural conditions. For this purpose, samples of non-woven fabrics were immersed in water for one hour. Once the samples were removed from water and the gravitational water oozed away, they were weighed and spread on a laboratory table to dry at room temperature of 20°C. During drying, the non-woven fabrics were weighed once again after 24 h to determine the rate of water evaporation. After reaching air-dry condition, the dry matter content was determined by drying the fabrics at 105°C for 3 h. Based on the results, the mass of the retained water was calculated at time intervals, expressed as percentage figures. The penetration of water vapour through non-woven fabrics was assessed as follows: 500 cm^3 of water was poured into beakers with a diameter of 20 cm and covered with the fabrics. The beakers were weighed and placed on a laboratory table. Subsequent weighing of the beakers was conducted after 24 h. Based on the measurements, the mass of evaporated water was calculated. The seeds of *Lolium multiflorum* Lam. lawn variety "Inka" with germination capacity 85% were used for the study. The temperature in the laboratory room was around 20°C and the air humidity was 55–60%. The seeds *Lolium multiflorum* for germination were spread on thick moist paper and covered with individual fabrics. Humidity of the substrate was controlled daily and kept constant, replenishing water to a constant mass. Four and eight days after sowing, the test determined the percentage of seeds that germinated.

FIELD STUDIES

Three types of non-woven fabrics were used in the field study: two biodegradable ones (SB 17/12/2 and SB 43/12/4), one commercial grade, and hydrogel. The non-woven fabrics were selected based on their parameters determined during laboratory tests. Granulated hydrogel from "Artagro" Edward Kulikowski, commonly used in horticulture, was applied during the experiments. Results presented in this paper come from two experiments carried out in 2019. These experiments were set up on reconstructed parts of river embankments that had been damaged during the flood. The first experiment was located on the embankment of the Uszwica River in Kwików, which was built using material originating from brown soil. Substrate samples were taken from the 0–20 cm layer to determine chemical properties (see Table 1). This soil material had a slightly acid reaction, optimal for the development of the plant mixture used, as it was rich in organic substance, nitrogen, and magnesium, but was very poor in phosphorus and potassium. The experiment was located on the embankment facing south-west. The height of the embankment from the base to the top was 4 m, and the length of the slope was 7.5 m. The inclination of the embankment was 32.23°. The surface area of one plot was 22.5 m^2 (7.5 × 3.0 m). The second experiment was located on the embankment of the Vistula River in Kraków. This embankment was built from material originating from light, sandy soil. Chemical properties of this material are presented in Table 1. The soil material was slightly acidic, but very poor in basic minerals, especially nitrogen and phosphorus. The experiment was located on the embankment facing the south. The height of the embankment from the base to the top was 4.5 m, and the length of the slope was 10.0 m. The inclination of the embankment was 26.74°. The surface area of one plot was 20 m^2 (10.0×2.0 m).

Table 1. Chemical properties of soil in the study area

Place	pH		Total N	Organic C	P_2O_5	K_2O	Mg
	H_2O	KCl	$g \cdot kg^{-1}$ of soil		$mg \cdot kg^{-1}$ of soil		
Kwików	6.52	5.85	1.5	4.7	21.0	62.3	none
Kraków	6.41	5.34	0.8	6.8	12.0	112.0	66.0

Source: own elaboration.

In both experiments, a grass-legume mixture was used for sowing the surface of the embankments, the composition of which is shown in Table 2.

Table 2. The share of individual species in the grass-legume mixture

Species	Variety	Share in the mixture (%)	Rate of sowing ($kg \cdot ha^{-1}$)
Lolium perenne L.	Bokser	20	10
Poa pratensis L.	Skiz	30	7
Festuca rubra L.	Adio	25	8
Festuca arundinacea Schreb.	Rahela	10	6
Trifolium repens L.	Romena	15	3

Source: own elaboration.

The experiments were set up in the second half of April 2019, and each included the following six treatments in three repetitions:
A – control,
B – $N_{30}P_{30}K_{50}$,
C – $N_{30}P_{30}K_{50}$ + hydrogel (0.5 $kg \cdot m^{-2}$),
D – $N_{30}P_{30}K_{50}$ + commercial non-woven fabric,
E – $N_{30}P_{30}K_{50}$ + biodegradable non-woven fabric (SB 17/12/2),
F – $N_{30}P_{30}K_{50}$ + biodegradable non-woven fabric (SB 43/12/4).

After sowing the seed mixture, treatments D, E and F were covered with non-woven fabrics for a period of two months. Fertilisers and hydrogel were mixed with the soil before sowing the mixture. Mineral fertilisation was applied as follows: nitrogen 30 kg $N \cdot ha^{-1}$ in the form of ammonium nitrate (34% N), phosphorus 30 kg $P_2O_5 \cdot ha^{-1}$ in the form of enriched superphosphate (40% P_2O_5), and potassium 50 kg $K_2O \cdot ha^{-1}$ in the form of potassium salt (56% K_2O).

In the year the experiments, in both regions, the meteorological conditions were as presented in Table 3.

Climatic conditions in the village of Kwików, where the first experiment was conducted on the embankment of the Uszwica River, were favourable for the emergence and growth of plants. During the growing season, from April to September, the total precipitation was 420.60 mm. Precipitation was fairly evenly distributed throughout the year. Mean air temperature was 6.6°C. In the first three months of plant growth, the Selyaninov hydrothermal index was as follows: 2.0 in April, 1.4 in May, and 1.3 in June. According to the above, April was quite humid, and May and June were optimal. This coincides with the assessment of pluvio-thermal conditions in Poland in spring in 1971–2000. In that period, the southern part of the Małopolska Upland was considered the most humid (Skowera and Puła, 2004).

In the case of the experiment conducted on the embankment of the Vistula River in Kraków, the conditions for plant

Table 3. Distribution of precipitation and temperature in the year of settling up the experiment (2019)

Month	Place			
	Kwików		Kraków	
	precipitation (mm)	temperature (°C)	precipitation (mm)	temperature (°C)
Jan	83.1	−1.3	51.9	−1.3
Feb	78.0	−7.2	22.1	1.5
Mar	68.7	5.1	17.9	5.0
Apr	64.5	10.7	64.7	10.1
May	67.5	15.2	22.8	15.0
Jun	73.9	18.5	143.1	17.7
Jul	68.6	21.0	60.7	20.5
Aug	71.0	19.3	0.0	19.3
Sep	75.4	15.2	47.8	15.4
Oct	82.1	9.3	122.8	−9.2
Nov	83.3	6.7	22.1	5.2
Dec	84.1	−1.7	27.2	−2.9
Total	899.9	–	647.0	–
Mean	–	9.2	–	8.9

Source: own elaboration.

emergence were extremely unfavourable, especially in May. This resulted in seedlings dying off. In May, the Selyaninov hydrothermal index was 0.5, which classifies this month as very dry. Due to the large number of dry seedlings in this experiment, the soil was scarified again and a modified mixture was sown. *Lolium perenne* was replaced with *Dactylis glomerata* as this species grew well on the remaining surface of the embankment. In August and September, humidity for the emergence and growth of plants was also not favourable. Based on the value of the Selyaninov hydrothermal index, August was dry and September quite dry.

In the first experiment, vegetation was mowed twice in the year of sowing. The assessment of the floristic composition and the state of soil sodding was carried out for the first time two months after sowing the seeds, and for the second time in the second half of September 2019, before the second mowing of plants. In the second experiment, plants were mowed once in the year of sowing. The assessment of the floristic composition and the state of sodding was carried out for the first time in June, and for the second time after second sowing, at the beginning of October 2019. In 2020 and 2021, in both experiments, plants were mowed only once at the end of June, and at that time the floristic composition and the degree of sodding was assessed. Each time, the plants were mowed at the beginning of Poaceae flowering and the mulched plant mass was left to decompose. The biomass was a source of nutrients for plants in the next period. The assessment of the floristic composition was performed using the Klapp method, and the state of sodding was assessed using the Weber squares method.

All the analyses were carried out in at least three independent series of repetitions. The results were statistically analysed using the ANOVA module of Statistica 12.0 PL software. Statistical calculations were based on the results from each variant and each replication or plot (n = variants × replications).

The significance of differences was assessed using Tukey's HSD test, assuming a significance level of $p = 0.05$.

RESULTS

LABORATORY TESTS

The assessment of non-woven fabrics parameters is presented in Tables 4–6. Table 4 provides results concerning the basis weight of non-woven fabrics and their water vapour permeability. Commercial non-woven fabrics had a much lower basis weight compared to biodegradable fabrics. Summer commercial non-woven fabric "S" had a particularly small basis weight. It was 3 times lighter than the winter "W" and 4–7 times lighter than the basis weight of the biodegradable fabrics. Non-woven fabric SB/43/12/4 had the largest basis weight. This fabric let through the least water vapour (49.9 g). The summer non-woven fabric "S" exhibited the highest permeability of water vapour. It let through 78 g of water vapour, which is 1.5 times more than the biodegradable fabric SB/43/12/4. Other types of fabrics generally had similar water vapour permeability, within the two values mentioned above.

Other evaluated parameters included the amount of water absorbed by non-woven fabrics and the amount of water evaporated after 24 h at 20°C (Tab. 5). Winter non-woven fabric "W" retained the most water after being soaked. It increased its basis weight more than 3 times, which was 311% in relation to the dry state, but after 24 h it was air dry. Summer commercial non-woven fabric "S" was characterised by low absorbency. After being soaked with water, biodegradable fabrics increased their basis weight 2.3–2.7-fold (230–270%). After 24 h, non-woven fabrics SB/17/12/2 and SB/43/12/4 lost the least water. The basis weight of was about 65% and 37% higher than the initial state (dry), respectively.

The strength and germination energy of the seeds of the *Lolium multiflorum* covered with non-woven fabrics are presented

Table 4. Basis weight of non-woven fabrics and amount of water vapour passing through them

Type of fabric	Basis weight of fabric ($g \cdot m^{-2}$)	Mass of beaker with water		Amount of evaporated water
		initial state	after 24 h	
		g		
Commercial "S"	17.0	245.4	167.4	78.0
Commercial "W"	50.0	249.0	181.3	67.7
SB 17/12/2	72.8	244.6	188.7	55.9
SB 38/12	91.5	246.1	199.6	56.1
SB 43/12/7	93.0	248.2	184.7	63.5
SB 43/12/5	94.0	252.2	194.7	57.5
SB 43/12/4	114.0	249.5	199.6	49.9

Explanations: "S" = summer non-woven fabric, "W" = winter non-woven fabric, SB = biodegradable non-woven fabric.
Source: own study.

Table 5. Amount of water retained by fabrics after 24 h

Type of fabric	State		
	initial (g)	after soaking	after evaporation
		%	
Commercial "S"	0.40 a	216 a	103 a
Commercial "W"	1.08 b	311 d	100 a
SB 17/12/2	1.75 c	270 c	163 b
SB 38/12	1.75 c	254 c	126 b
SB 43/12/7	2.00 d	223 b	123 b
SB 43/12/5	2.22 d	233 b	109 a
SB 43/12/4	2.48 d	233 b	137 b

Explanations: "S", "W", SB as in Tab. 4; values in columns marked with the same symbol do not differ significantly at p = 0.05.
Source: own study.

Table 6. Share of germinated seeds of *Lolium multiflorum* L. covered with non-woven fabrics

Type of fabric	Time since sowing	
	4 days	8 days
	%	
Commercial "S"	65.6 d	75.3 b
Commercial "W"	45.0 b	80.2 b
SB 17/12/2	51.9 c	90.7 c
SB 38/12	4.0 a	35.8 a
SB 43/12/7	30.3 b	75.7 b
SB 43//125	4.5 a	90.4 c
SB 43/12/4	70.1 d	99.6 c

Explanations: "S", "W", SB as in Tab. 4; values in columns marked with the same symbol do not differ significantly at p = 0.05.
Source: own study.

in Table 6. Four days after sowing, the largest number of seeds germinated under SB/43/12/4 biodegradable fabric and summer "S" fabric. As much as 70% of the seeds germinated under the first fabric, and 65% under the second one. The smallest number of seeds germinated under biodegradable fabric SB/38/12, both after four days and after eight days. On the first date, 4% of seeds had germinated under the biodegradable fabric, and by the second date, this increased to 35%. In comparison, the number of germinated seeds under other types of fabrics ranged from 30% to 51% four days after sowing. Eight days after sowing, the largest share of germinated seeds was found under biodegradable fabrics SB/43/12/4, SB/17/12/2, and SB/43/12/5. In the first case, this percentage was 99%, and in the second and third it was 90%.

FIELD STUDIES

• First experiment

At the time of the first assessment of the vegetation condition, carried out two months after sowing, it was established that *Lolium perenne* had the largest share in the soil surface coverage, followed by *Festuca rubra* and *F. arundinacea* (Tab. 7). *Trifolium repens* and *Poa pratensis* had a small share in the coverage. The share of these species in soil coverage was 3.8%, and from trace amounts to 2%, respectively. However, there were clear differences in the coverage of the soil surface by individual species between treatments covered with a non-woven fabric in the initial period of development and ones without a fabric, in favour of the former. In treatments covered with non-woven fabrics, sown species covered the soil surface in 65%, and 41–45% in treatments without the cover. Covering the soil after sowing with fabrics particularly favourably affected the emergence of *Lolium perenne* and *Festuca rubra*, while limiting the development of native species, especially *Convolvulus arvensis*, *Chenopodium album* and *Cirsium arvense*, which occurred in large quantities when non-woven fabric was not used.

During the second assessment, carried out before the second mowing of plants in mid-September 2019, the treatments covered with a non-woven fabric showed no major differences in the proportion of individual species compared to their quantities at the time of the first assessment during the initial development period (Tab. 7). However, the degree of sodding increased by 15–20%, due to the loss of native species. In the treatments without non-woven fabric, an increase in *Lolium perenne*, *Festuca arundinacea* and *Festuca rubra* took place at the expense of native species, such as *Elymus repens*, *Convolvulus arvensis,* and *Cirsium arvense*. Soil surface sodding also increased significantly in those treatments, by 10–17% in relation to sodding determined at the first assessment.

The analysis of floristic composition, carried out in the third year after sowing, revealed generally two types of sward (Tab. 7). One type was recorded in the control treatment (A), and the other one in the remaining treatments (B, C, D, E, F), which were fertilised (NPK) in the first year. In the control treatment, the sown species accounted for about 65% of the sward yield, and 76% in the fertilised treatments, native species constituted the rest of the yield. In the first year, there was a considerable decrease in the number of dominant species, such as: *Convolvulus arvensis*, *Chenopodium album*, *Cirsium arvense*, whereas *Rumex obtusifolius* and *Geranium pratense* became dominant. *Festuca arundinacea* accounted for 42–57% of sward yield and was the prevailing species, whereas *Festuca rubra* was second, with a 11–15% share in the yield. The remaining three species in the mixture: *Lolium perenne*, *Poa pratensis* and *Trifolium repens* had a share from trace amounts to 5% each. The share of *Lolium perenne* decreased as much as five times in relation to the first year. Noteworthy is the appearance of *Phalaris arundinacea* in the assessed communities. The soil sodding state on all variants was high, about 98%.

• Second experiment

Spring sowing of the grass-legume mixture on the embankment in Kraków did not bring the expected effect (Tab. 8).

Plant emergence was extremely weak. Two months after sowing, only a small number of *Festuca arundinacea* seedlings appeared, and these were in minimal quantities. The soil cover by this species was 4–5%. As regards the remaining sown species, red fescue and perennial ryegrass occurred in trace amounts. Their coverage of soil surface did not exceed 2%. However, in larger quantities, native species appeared, mainly *Elymus repens* and *Chenopodium album*. Their share in the soil surface coverage was 2–3 times greater than the soil coverage by the sown species.

Table 7. Floristic composition and degree of sodding (in %) on the embankment of the Uszwica River in Kwików

Species	2019												2021	
	treatment													
	A		B		C		D		E		F		A	mean for B, C, D, E, F
	assessment													
	I	II	I	II	I	II	I	II	I	II	I	II		
Sown species														
Lolium perenne L.	15	20	18	18	16	20	26	26	26	27	28	28	–	–
Festuca arundinacea Schreb.	10	16	13	48	16	16	16	16	16	18	17	17	42	57
Festuca rubra L.	9	8	10	14	10	12	13	14	15	15	15	14	15	11
Poa pratensis L.	1	1	1	+	+	1	+	2	+	1	2	2	2	5
Trifolium repens L.	3	3	4	3	4	4	6	4	8	6	7	6	+	–
Native species														
Elymus repens (L.) Gould	11	8	11	9	9	8	7	8	5	7	5	7	10	7
Arrhenatherum elatius L.	4	2	4	2	4	2	–	–	+	2	1	2	5	3
Dactylis glomerata L.	1	1	1	1	1	2	–	–	+	1	+	2	2	2
Phalaris arundinacea L.	–	–	–	–	–	–	+	1	–	+	–	–	–	–
Convolvulus arvensis L.	20	17	16	15	16	15	10	12	12	10	12	10	2/2	3/3
Chenopodium album L.	14	14	15	14	15	13	14	12	10	8	10	8	2	1
Cirsium arvense (L.) Scop.	8	6	5	4	4	4	2	+	2	2	2	2	–	+
Equisetum arvense L.	2	2	2	1	2	2	2	+	1	1	+	1	+	+
Urtica dioica L.	–	1	–	+	+	+	+	1	1	+	1	1	2	1
Rumex obtusifolius L.	–	1	+	+	–	+	+	1	+	1	–	1	5	3
Geranium pratense L.	–	–	–	–	–	–	–	–	–	–	–	–	4	2
Stellaria graminea L.	–	–	–	–	–	–	–	–	–	–	–	–	3	1
Sodding (%)	40	52	42	59	45	59	63	78	60	80	65	82	98	98

Explanation: A = control, B = $N_{30}P_{30}K_{50}$, C = $N_{30}P_{30}K_{50}$ + hydrogel (0.5 kg·m^{-2}), D = $N_{30}P_{30}K_{50}$ + commercial non-woven fabric, E = $N_{30}P_{30}K_{50}$ + biodegradable non-woven fabric (SB 17/12/2), F = $N_{30}P_{30}K_{50}$ + biodegradable non-woven fabric (SB 43/12/4).
Source: own study.

Table 8. Coverage of soil surface by plant species (%) on the embankment of the Vistula River in Kraków in 2019

Species	Treatment					
	A	B	C	D	E	F
Sown species						
Festuca arundinacea Schreb.	5	4	4	5	5	5
Lolium perenne L.	+	+	+	1	2	1
Festuca rubra L.	1	2	1	1	1	2
Poa pratensis L.	–	–	–	–	–	–
Trifolium repens L.	–	–	–	–	–	–
Native species						
Elymus repens (L.) Gould	8	10	8	7	8	7
Chenopodium album L.	5	4	3	3	4	3
Equisetum arvense L.	1	1	2	1	1	1

Explanations: A, B, C, D, E, F as in Tab. 7.
Source: own study.

In the weeks that followed, no improvement in the state of sodding was determined. Therefore, in the last decade of July, a new mixture was re-sown, where *Lolium perenne* was replaced with *Dactylis glomerata*. After two months from sowing (end of September), the condition of the seedlings was satisfactory. The sown species accounted for 56–70% of the aboveground mass. *Dactylis glomerata* had the largest share, followed by *Festuca arundinacea* (Tab. 9).

Among the native species, *Elymus repens* and *Chenopodium album* had the largest share in the aboveground mass. These two species accounted for approximately one third of the aboveground mass yield. In general, there were no major differences in the floristic composition in sward between the treatments not covered with fabrics (A, B and C). On the other hand, in treatments covered with non-woven fabrics (D, E, F), quantitative changes in the share of some species were observed. Covering the soil with a non-woven fabric after sowing had a positive effect on the emergence of *Festuca rubra*, *Trifolium repens*, and to a lesser extent on *Dactylis glomerata*. The amount of *Trifolium repens* in the treatments covered with a non-woven fabric was 1.5–2 times

Table 9. Floristic composition and soil surface sodding (%) on the embankment of the Vistula River in Kraków

Species	2019						2022	
	Treatment							
	A	B	C	D	E	F	A	mean for B, C, D, E, F
Sown species								
Dactylis glomerata L.	20	20	22	25	23	28	30	30
Festuca arundinacea Schreb.	18	16	14	16	17	16	26	41
Festuca rubra L.	10	13	14	16	17	17	12	8
Poa pratensis L.	2	3	2	3	3	3	5	3
Trifolium repens L.	6	5	5	8	10	8	5	+
Native species								
Elymus repens (L.) Gould	25	27	25	26	23	22	20	16
Chenopodium album L.	10	10	11	5	6	5	–	–
Convolvulus arvensis L.	8	4	5	+	+	+	+	+
Equisetum arvense L.	1	1	1	+	+	+	+	+
Stellaria graminea L.	–	–	–	–	–	–	1	–
Sodding (%)	68	70	70	85	85	83	96	95

Explanations: A, B, C, D, E, F as in Tab. 7.
Source: own study.

higher, and of *Festuca rubra* almost by one third higher compared to the treatments without a non-woven fabric. The use of a non-woven fabric limited mainly the development of *Convolvulus arvensis*. At the same time, the treatments covered with a non-woven fabric had 10–15% better surface sodding compared to the treatments without a non-woven fabric.

Three years after development, as in the first experiment, the experiment distinguished two types of surfaces differing in their floristic composition. The first type was the control treatment, and the second type – other NPK fertilised treatments. On both surfaces, *Dactylis glomerata* and *Festuca arundinacea* were the dominant species. *Dactylis glomerata* constituted approximately 30% of sward yield on both surfaces. The share of *Festuca arundinacea* on the unfertilised surface was 26%, and 40% on the fertilised surface. It means that grass propagation was in progress. This species reaches full yield most often after 3 years after sowing. Among the sown species, *Festuca rubra* was ranked third in terms of quantity, with its share of 12% on the non-fertilised surface and 8% on the fertilised surface. The share of *Poa pratensis* in the yield was 3–5%, and *Trifolium repens* ranged from trace amounts to 3% of sward yield. On both types of embankment surfaces, the state of sodding was generally high, reaching about 95%.

DISCUSSION

Natural or synthetic non-woven fabrics used for soil stabilisation on the slopes counteract water erosion and have a beneficial effect on the plant community, including biodiversity and species composition, both in natural succession and after sowing the reclamation mixtures (Patrzałek, 2003; Broda *et al.*, 2018; Kobiela-Mendrek *et al.*, 2019). High water absorption and relatively slow water removal by two biodegradable non-woven fabrics minimised the fluctuations in substrate moisture and temperature. Therefore, it was established that using them to cover the soil after sowing would ensure better conditions for the emergence and in the initial period of plant development. However, no differences were found in the development of plants covered with those fabrics and the commercial fabric, which was the result of optimal humidity conditions in the first experiment, and extremely dry conditions in the second experiment. At the same time, such humidity conditions presumably determined the lack of a beneficial effect of the hydrogel on seedlings development. Hydrogel is considered to be a moisture buffer as it reduces water stress in plants. Its beneficial effect on plant development has been reported by many researchers (Hayat and Ali, 2004; Faligowska and Szukała, 2011; Księżak, 2018; Špitalniak *et al.*, 2019). However, the use of non-woven fabrics to cover the soil after sowing the seeds significantly accelerated the emergence and soil sodding by *Lolium perenne*, *Trifolium repens* and *Festuca rubra*. Thereby, the risk of occurrence of soil erosion and washing off of the sown seeds was reduced (Klima and Wiśniowska-Kielian, 2006; Kacorzyk, Kasperczyk and Szewczyk, 2018). At the same time, covering the soil with a non-woven fabric limited the development of certain weeds: *Convolvulus arvensis* and *Chenopodium album*. This was the result of a lower access to light, lower temperature, and competition from the sown plants. *Convolvulus arvensis* is an extremely light-loving species, whereas high temperature favours the growth of *Chenopodium album*.

Despite the relatively small difference in the impact of natural non-woven fabrics on the growth rate and the amount of plant biomass produced compared to a synthetic fabric, their use is more environmentally friendly. One year after application, natural non-woven fabrics, which are based on wool, bird feathers or cotton, show weakening of mechanical parameters, because they are biodegradable. Thus, they become a source of nutrients, mainly nitrogen for plants, e.g. from the decomposition of keratin (Vončina and Mihelič, 2013; Kacorzyk, Strojny and Białczyk, 2021; Li, 2022; Broda *et al.*, 2023). In contrast, synthetic non-woven fabrics do not exhibit such features. They finally become burdensome waste, and when exposed to ultraviolet radiation, abrasion or oxidation, they are subject to fragmentation and are the source of soil and plant pollution with macro- and microplastic particles (Prambauer *et al.*, 2019; Kopitar *et al.*, 2022). This is of particular importance in the case of cultivations using covers. While contamination of ocean waters with microplastics (<5 mm) and nanoplastics (<1 μm) has been thoroughly examined, soil and plant pollution has so far been studied to a limited extent. Piehl *et al.* (2018) were first to quantitatively estimate the contamination of agricultural land with macro- and microplastics in Germany. They determined that dry soil mass contains 206 macroplastic particles and, on average, 0.34 microplastic particles per 1 kg. Yang *et al.* (2021) and Campanale *et al.* (2022) attempted to assess the sources of microplastic, its occurrence, and threat to soils and plants. Microplastic can migrate to soils and plants from agricultural production, such as cultivation under covers, ballots for silage preparation and seedling protection, especially in the case of long-term use. Other sources include urban and industrial areas and road networks. The content of microplastic reaches even up to 42,960 pieces·kg^{-1} soil, and daily consumption of microplastic by adults in edible parts of fruit and vegetables reaches up to 233 particles·kg^{-1} (Campanale *et al.*, 2022). At the same time, the use of organic materials, which are by-products of agricultural activity, to manufacture non-woven fabrics may be crucial for the circular economy (European Parliament resolution, 2021).

A very small share of the low grasses sown: *Poa pratensis*, *Lolium perenne* and *Festuca rubra*, in the coverage of the surface of the embankments was determined in this study. It resulted from a rare one-time mowing in the second and third year, which favoured the development of tall grasses, i.e. *Festuca arundinacea* and *Dactylis glomerata*, overshadowing the low grasses. This one-time mowing of embankments allows to reduce the expenditure. However, in the case of their reconstruction or building, it is advisable to use *Lolium perenne* for sowing as it is a quickly sodding species. Thus, it reduces the possibility of erosion and seeds being washed out. The small share of *Trifolium repens* in the sward depended on local conditions which did not meet the requirements of this species for germination and further development, despite the use of supporting materials.

The beneficial effect of NPK fertilisation on the species composition within the communities was visible only in the second and third year after sowing. Therefore, it should probably be associated with the effect of phosphorus fertilisation, since soils in both experimental treatments were very poor regarding nutrient content. The scarcity of phosphorus in the soils results from the low content of this nutrient in upland soils and subsequently in river (flood) waters, since this component is not very susceptible to leaching from the soil (Kacorzyk, 2018). Helsinki Convention Research indicates that the main rivers in Poland discharged (with water) about 15 thous. Mg of phosphorus into the Baltic Sea in 2010. However, this amount is systematically decreasing, and in 2021 it reached 6.4 thous. Mg, due to the fact that the length of the active sewage network increased in that period by 75% (GUS, 2023). In this study, as a result of plant mulching, phosphorus cyclically returned to the soil after fertilisation. This favoured the development of vegetation. On the other hand, the greater abundance of soils of river embankments in nitrogen and potassium is a result of periodical enrichment of the soil with these nutrients by flood waters. Flood waters are rich in nitrogen compounds owing to their larger presence in the aquatic environment due to the high susceptibility to leaching deep into the soil profile, from where they move to surface waters, particularly in the post-harvest period (Igras, 2004; Wiśniowska-Kielian and Niemiec, 2006b). Although potassium is found in water in relatively small concentrations, several times lower than other basic cations, owing to its low susceptibility to leaching. However, it can originate from alluvion left after flooding, as a result of soil erosion in the catchment area (Wiśniowska-Kielian and Niemiec, 2006a).

CONCLUSIONS

Covering the soil with non-woven fabrics after sowing had a positive effect on the initial growth of plants, accelerating their emergence and the degree of surface sodding. This reduced the risk of seeds being washed out. The type of non-woven fabrics and hydrogel used generally did not affect the initial development of the plants. The lack of differences in the impact of non-woven fabrics and hydrogel on plant development was due to the moisture levels in the substrate after seed sowing. In the first experiment, those conditions were optimal, and in the second one these were extremely dry. Pre-sowing mineral fertilisation had a beneficial effect on the initial and subsequent development of plants. When developing river embankments located on soils with scarcity of certain nutrients, it is necessary to enrich them through fertilisation.

The best species to use in mixtures for sodding degraded flood embankment surfaces are *Festuca rubra*, *Poa pratensis* and *Trifolium repens*, because they have low nutritional requirements. They generally tolerate a site with periodic droughts and do not create a large above-ground mass, but strongly stabilise the substrate by producing a large root mass. Only in some cases can the use of *Dactylis glomerata* be recommended. It is recommended to use fertilisation as in the study to ensure proper development of plants and at the same time prevent pollution of rivers. In the event of failure to create turf, the mixture should be re-sown.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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