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Assessment of the effectiveness of overseeding methods for hardwood meadows under various pluviothermal conditions

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Abstract: The aim of this study is to evaluate the effects of improving the state of hardwood meadows using two methods of overseeding: strip-till and disc seeding (Vredo), with mixtures of grass and legume seeds under diverse pluvial and thermal conditions in eastern and central Poland. The field experiments were conducted in three farms: Zimna Woda (experiment I), Racibory (experiment II), and Ranna (experiment III). The measures to improve permanent grassland (PG) were carried out after the second cut in 2016 and in spring 2017. The effectiveness of both methods was evaluated based on changes in the botanical composition of the sward and the yield of total protein and soluble sugars (Preś and Rogalski, 1997). Positive effects of both methods on the floristic composition were achieved in 2017 in all meadow habitats on mineral soils: brown soils formed from loamy sand (Zimna Woda), proper brown soils (Racibory) on light and medium loam, and alluvial soils on light loam (Ranna). Despite adverse pluvial and thermal conditions, both methods improved the utility value of the sward, increasing the yields of dry matter, protein, and soluble sugars in subsequent years. The study showed that improving the state of PG by overseeding with diploid and tetraploid grass varieties and legume plants is effective, with its level of effectiveness depending on the pluvial and thermal conditions after treatment.

Keywords: dry matter yield, effects of overseeding, evaluation of botanical composition, hardwood meadows, protein, soluble sugars

INTRODUCTION

The basic condition for maintaining a favourable species composition of grass communities is systematic fertilisation and utilisation (Deak *et al.*, 2007). Limiting or completely abandoning these treatments, as well as improper air-water conditions, cause unfavourable floristic changes. The process of degradation of grass communities in meadows and pastures leads to a gradual decrease in their utility value (Novak, 2004). This phenomenon concerns both yield and the biological value of fodder as an essential factor in animal nutrition. The main factors that diminish the floristic composition of meadows and pastures include the decline in natural soil fertility due to the lack or reduction of NPK fertilisation and improper proportions relative to soil fertility and plant nutritional needs, continued drying of habitats, and errors in utilisation. The declining utilisation of meadows and pastures (Baryła, 1996; Barszczewski, 2015) has intensified these phenomena in recent years. Deterioration of habitat conditions, particularly soil trophicity and moisture, increases the share of undesirable vegetation in grass communities. Usually, these communities are dominated by plants with strong taproot systems and the highest ability to use nutrients, mainly dicotyledonous plants classified as herbs and weeds increasing their biodiversity (Plantureux, Peeters and McCracken, 2005), as well as grasses of low utility value. Conversely, valuable grass and the legume species disappear.

A radical method of improving the floristic composition of the sward, involving the complete destruction of old turf and re-seeding, is the full cultivation method (Barszczewski, Jankowska-Huflejt and Twardy, 2015; Czerwiński and Golińska, 2015).

However, due to the cost of implementation and environmental impacts, such as reduced biodiversity and excessive nutrient release, full cultivation is performed only where other renovation methods are ineffective. A relatively inexpensive and effective method of renovating grasslands by introducing seeds of valuable grass and legume species and varieties into the turf is overseeding (direct seeding method) (Goliński, 2008; Terlikowski, 2014; Barszczewski, Jankowska-Huflejt and Twardy, 2015). One of the factors determining the success of this treatment is the technique of its implementation (Goliński, 1998). Effectiveness also depends on the selection of grass and legume species (Goliński and Golińska, 2008; Golińska and Goliński, 2023) and varieties, as well as the floristic composition of the existing sward (Kozłowski, 1998). The success of PG renovation through overseeding is also determined by the timing of implementation and the course of meteorological conditions (Bartmański and Mikołajczak, 1995; Kitczak and Dobromilski, 1995; Grzegorczyk, 1998; Baryła and Kulik, 2011; Baryła and Kulik, 2012). Therefore, grasslands in proper hardwood habitats are particularly difficult to renovate. They rely mainly on rainfall, making overseeding renovation risky due to moisture deficits in the topsoil. Insufficient moisture results in poor emergence or even seedling desiccation (Janicka, 2012; Wasilewski, 2015).

Since permanent grasslands in hardwood habitats constitute about 40% of the permanent grassland area in Poland, an attempt was made to assess the effects of their renovation by overseeding using tetraploid grass varieties and legume plants adapted to habitat conditions and utilisation methods. The aim of the study is to compare the effects of improving the floristic composition of permanent grassland in hardwood meadows by direct seeding using a strip-till and disc seeder (Vredo) with intensive grass mixtures including tetraploid varieties and legume plants (Carranca, Torres and Madeira, 2015; Kebede, 2021) under diverse pluvial and thermal conditions and soil conditions in eastern and central Poland.

MATERIALS AND METHODS

LOCALISATION OF EXPERIMENTS

The study was implemented from 2016 to 2020 and involved permanent grasslands in three farms in eastern and central Poland.

Experiment I was conducted on a farm in Zimna Woda (51°47'59" N, 22°14'24" E) in the Lublin Province, Łuków County, on brown soils formed from slightly loamy sand. The grasslands in the farm were facultative, used for haymaking, showing variable soil phosphorus content from medium to high, and potassium at a low level. According to the grassland classification, they are classified as periodically dry proper hardwood habitats. The grass-herb communities were dominated by: *Lolium perenne* L., *Dactylis glomerata* L., *Phleum pratense* L., *Festuca arundinacea* Schreb., and *Elymus repens* (L.) Gould. The significant 15% share of dicotyledonous weeds indicated the need for selective spraying before overseeding.

Experiment II was established in a farm in Racibory (53°23'12" N, 22°26'0" E) in the Podlaskie Province, Grajewo County, on proper brown soil built from light and medium loam. The entire grasslands were used for mowing, located on leached brown soil from medium loam, mainly with high phosphorus content and low to medium potassium. The grasslands were classified as proper hardwood habitats. The plant community covering the approximately 15-year-old meadow was dominated by *Dactylis glomerata*, *Festuca rubra* L., and *Poa pratensis* L., with a significant 20% share of dicotyledonous plants, indicating the need for weed control through spraying.

Experiment III was located in Ranna (52°14'59" N, 18°24'17" E) in the Greater Poland Province, Konin County, on alluvial soil formed from light loam. Most of the grasslands were characteristic of proper hardwood habitats with high phosphorus content and potassium ranging from low to high. The grass-herb community in this farm was dominated by *Poa pratensis*, *Festuca pratensis* L., *Dactylis glomerata*, and *Holcus lanatus* L., with a significant 25% share of herbs and weeds, mainly *Taraxacum officinale* L.

The low soil pH of approximately 4.5 in Zimna Woda and slightly above 5.0 to 5.5 pH in the other two farms indicated the need for liming, which was performed after the second or accelerated third cut. Carbonate-magnesium lime containing 32% CaO and 20% MgO was used, depending on the pH, from 15 to 30 t·ha^{-1}. Table 1 shows the NPK fertilisation used on all farms in 2016–2020.

Table 1. The average annual NPK fertilisation rate (kg·ha^{-1}) applied to grassland

Fertiliser	Dose of nutrient in experiment		
	I	II	III
Nitrogen (N)	160	120	160
Phosphorus (P)	50	45	25
Potassium (K)	130	100	140
Form of fertiliser	mineral	mineral and manure	mineral and slurry

Source: own elaboration.

In each farm, a field experiment, known as a production experiment (Walewski, 1989), was established with the following sites: permanent grassland (PG) subjected to renovation by direct seeding using appropriate mixtures (Tab. 2), with a strip-till seeder and disc seeder (Vredo) in late summer 2016 (second half of September) and spring 2017 (first half of April). For the purpose of conducting feeding experiments in individual farms, the grasslands were overseeded with an appropriate mixture of grass and legume seeds over an area of 8 to 9 ha, considering their soil conditions.

The effects of the applied methods for improving PG were evaluated from 2017. On each delineated plot, four subplots of 20 m^2 each were marked, where trial cuts were made. The cut sward from each subplot was weighed, and samples were taken to determine yield and for chemical analyses. The number of samples in the growing season depended on the number of cuts in a given year limited in pluvial and thermal condition. Before the first cut, the botanical composition of the sward was assessed using the estimation-measurement method according to Klapp (1962), dividing into two groups: sown + native species and only native species. The utility value numbers of the sward (Uvn) was assessed according to Filipek (1973), Novak (2004), based on the

Table 2. Composition of seed mixtures used for meadow sward renovation used in experiments

Species	Ploidity	Composition of seed mixtures (%) in experiment		
		I	II	III
Lolium hybridum	T[1]	15	10	10
Festulolium	T	10	20	15
Lolium perenne	T	15	–	15
Festuca pratensis	D[2]	10	15	15
Dactylis glomerata	D	10	5	5
Phleum pratense	D	–	5	5
Poa pratensis	D	5	5	5
Lolium perenne	D	10	10	–
Trifolium pratense	D	15	20	20
Lotus corniculatus	D	10	10	10
Summary		**100**	**100**	**100**

Source: own elaboration.

percentage share of each species in the yield and its utility value, considering the following ranges of utility value numbers (Uvn):
- 90 to 100 points – highly valuable,
- 70 to 90 points – valuable,
- 50 to 70 points – less valuable,
- 25 to 50 points – least valuable,
- 15 to 25 points – worthless,
- 0 to 15 points – deleterious,
- <0 points – toxic.

In green forage samples (after drying and grinding), the content of total protein and soluble sugars was determined using the NIRS method (PN-EN ISO 12099, 2013) on a NIRFlex N-500 device, with ready-made calibrations from INGOT® (Gaweł and Grzelak, 2020). Based on the dry matter yield and the content of total protein and simple sugars, annual yields of protein and sugars were calculated. The obtained results of total protein and soluble sugar yields were statistically evaluated using one-way analysis of variance and Tukey's test to distinguish homogeneous groups among the compared means with the p value equal 0.05.

PLUVIAL AND THERMAL CONDITIONS

One of the main factors determining the success of the applied renovation methods in the studied farms was the course of meteorological conditions, especially the amount and distribution of rainfall and average daily air temperatures during the decade. It is assumed that the optimal average daily temperature for the growth and development of grass vegetation ranges between 15–18°C, with daytime temperatures around 20–22°C and night-time temperatures around 12°C. Under strong sunlight and higher temperatures, the intensity and duration of tillering are significantly limited, and above 30°C, this process stops (Jewiss, 1972). To assess the pluvial and thermal conditions during the growing seasons from 2017 to 2020 in the discussed farms, the Selyaninov hydrothermal coefficient (Skowera and Puła, 2004) was used, calculated as:

$$k = \frac{10P}{\sum t} \tag{1}$$

where: P = monthly sum of atmospheric precipitation (mm), Σt = monthly sum of average daily air temperatures >0°C.

Each month of the growing season was characterised based on the coefficient k as:
- extremely dry: $k \leq 0.4$,
- very dry: $0.4 < k \leq 0.7$,
- dry: $0.7 < k \leq 1.0$,
- fairly dry: $1.0 < k \leq 1.3$,
- optimal: $1.3 < k \leq 1.6$,
- fairly moist: $1.6 < k \leq 2.0$,
- moist: $2.0 < k \leq 2.5$,
- very moist: $2.5 < k \leq 3.0$,
- extremely moist: $k > 3.0$.

Based on coefficient k values ($k \leq 1$), periods of drought were identified as times when the grassland sward evaporated twice as much water as it received from precipitation. In each farm, different meteorological conditions were recorded during the research period, which significantly influenced the success of renovation and sward yield.

Experiment I in Zimna Woda. In 2017, after the renovation treatments performed in April, soil moisture was appropriate, resulting in rapid emergence of the sown species. However, the following three months were quite dry, with further decline to dry conditions in August and very wet in September (Tab. 3). In the next year (2018), the amount and distribution of rainfall were factors limiting the biomass growth of the sward, with optimal conditions in April and alternating dry, fairly dry, and even very dry periods in the subsequent months of the season. In 2019, unfavourable conditions for sward growth in hardwood habitats continued, with only May and August showing optimal coefficient levels and the remaining months being fairly dry or extremely dry. Pluvial and thermal conditions in 2020, despite the dry period in April and very dry in July and August, were within the range of very wet or extremely wet for the remaining three months.

Experiment II in Racibory. In 2017, after overseeding, favourable pluvial and thermal conditions occurred at extremely wet and wet levels, appropriate for seed germination and the growth and development of grass and legume plant seedlings. In the following year, significantly worse conditions were observed, with optimal coefficient levels only in April and July, while the remaining months were very dry or dry once. In 2019, despite extremely dry conditions in April and dry conditions in June and fairly dry in September, May and August were fairly wet and July was wet. Much greater variation in pluvial and thermal conditions occurred in 2020: extremely dry in April and very dry in September, wet and fairly wet in May and August, and very wet in June, with a dry period in July.

Experiment III in Ranna. In 2017, during and after overseeding, favourable conditions significantly worsened to dry in May during the emergence period. In June and July, the coefficient levels increased to wet, and in August and September, they were extremely wet or very wet. In the following year (2018), in the first half of the growing season, the coefficient did not

Table 3. Pluviothermic extreme conditions in those farms (experiment I, II and III) in vegetation season (2017–2020) expressed by Selyaninov's coefficient (*k*)

Localisation	Year	Coefficient *k* and class of pluviotermic condition in month											
		Apr		May		Jun		Jul		Aug		Sep	
		value	class	value	class	value	class	value	class	value	class	value	class
Experiment I Zimna Woda	2017	3.9	em	1.1	fd	1.1	fd	1.3	fd	0.9	d	2.9	vm
	2018	1.4	o	0.8	d	1.2	fd	1.0	d	0.4	ed	0.9	d
	2019	1.2	fd	1.5	o	0.3	ed	0.5	vd	1.4	o	1.1	fd
	2020	0.9	d	2.9	vm	2.6	vm	0.6	vd	0.4	ed	3.1	em
Experiment II Racibory	2017	4.1	em	2.5	m	2.3	m	1.6	o	2.2	m	3.3	em
	2018	1.5	o	0.6	vd	0.4	ed	2.4	m	0.4	ed	1.0	d
	2019	0.2	ed	1.8	fm	0.8	d	2.2	m	1.4	o	1.1	fd
	2020	0.3	ed	2.0	fm	2.6	vm	0.8	d	1.8	fm	0.6	vd
Experiment III Ranna	2017	1.6	o	0.9	d	1.6	o	1.6	o	3.6	em	2.6	vm
	2018	0.9	d	0.9	d	0.8	d	1.4	o	0.4	ed	0.2	ed
	2019	0.5	vd	0.9	d	0.4	ed	0.9	d	0.7	vd	1.1	fd
	2020	0.1	ed	1.3	fd	0.9	d	1.1	fd	0.9	d	1.0	d

Explanations: ed = extremely dry, vd = very dry, d = dry, fd = fairly dry, o = optimal, fm = fairly moist, m = moist, vm = very moist, em = extremely moist.
Source: own elaboration based on agro-meteo stations: experiment I – Siedlce, experiment II – Białystok, experiment III – Konin.

exceed 1, indicating dry conditions. In July, it increased significantly to optimal, and in the next two months, it decreased sharply to extremely dry. Pluvial and thermal conditions in the middle of the 2019 season, in April, June, and August, ranged from extremely dry to very dry, with a slight improvement in May and July to dry and fairly dry in September. Moisture conditions in the 2020 growing season began with an extremely dry period, moving to optimal in May, and the coefficient levels in the next four months showed dry conditions three times and fairly dry once.

Unfavourable spring pluvial and thermal conditions, due to still small reserves of winter water and low temperatures, limited the biomass growth of the first cut to a small extent. However, severe water deficits during the summer became the main cause of poorer sward regrowth in subsequent cuts.

RESULTS

BOTANICAL COMPOSITION

Experiment I in Zimna Woda. The analysis of the species composition of the meadow sward in Zimna Woda (Tab. S1) at site 0 (without overseeding) also revealed the presence of native grass species that were sown on other sites with overseeding. These native species on this site were: *Festuca pratensis*, *Dactylis glomerata*, *Lolium perenne*, *Phleum pratense*, and *Poa pratensis*. In this group of grasses, the largest share in subsequent years was held by *Poa pratensis* and *Dactylis glomerata*, showing a declining trend. *Lolium perenne* showed a smaller share in the sward of this site, with an increasing trend in the last year to 9%, and *Phleum pratense* to 2%. In the group of other grasses on this site, *Holcus lanatus* dominated, constituting 19–20%, *Elymus repens* 14–16%, and each of the following species 2–6%: *Festuca rubra*, *Agrostis vulgaris*, *Deschampsia caespitosa*, *Anthoxanthum odoratum*, and *Poa trivialis*. The share of legume plants on this site was limited to *Trifolium pratense* from 2 to 1% in subsequent years. The share of herbs and weeds increased from 12% in 2017 to 15% in 2020, with the most numerous species (approx. 5%) being *Taraxacum officinale*, followed by *Persicaria maculosa*, *Cirsium arvense*, and *Plantago lanceolata*.

The species composition of native and sown grasses in the sward at sites with strip-till overseeding in summer 2016 (STU/Sm) and spring 2017 (STU/Sp) was richer by two species: *Festulolium* and *Lolium hybridicum*. The share of native and sown species on both sites, regardless of the overseeding date, showed little variation. Among the sown grass species, all showed an increase in share in the sward, with the largest increase due to overseeding observed in *Dactylis glomerata* and *Poa pratense*. In subsequent years up to 2020, most of these species maintained a similar share in the sward, with *Dactylis glomerata* showing a decreasing trend. The legume plant group on both sites was represented by two sown species: *Trifolium pratense* and *Lotus corniculatus*. In 2017, *Trifolium pratense* constituted 5–8% of the sward, with a clear increase to 13–12% in 2018, followed by a significant decrease in the next two years to 7 and even 4%. *Lotus corniculatus* at site STU/Sm constituted 3% in the first and second year, and 2% in the third and fourth year, while at site STU/Sp, its share in the sward was only 1%. The group of weeds on these sites was represented by the same species as on variant 0, as well as common *Stellaria media*, *Achillea millefolium*, and *Capsella bursa-pastoris*. Their total share was 7–9% in the first and second year, significantly increasing to 12 and even 17% in the following years.

The species composition of native and overseeded grasses in the sward at sites with disc seeder overseeding in summer 2016

(VU/Sm and spring 2017 (VU/Sp) was also richer by two species: festulolium and hybrid ryegrass. The share of these species in the sward ranged from about 1 to 5%, with festulolium occurring in quantities below 1% (individual plants) and hybrid ryegrass constituting 5% in the first year, showing a systematic declining trend in subsequent years. Among the native and sown grass species on both sites, cock's-foot dominated in the first year, with a share of 20% or more, showing a decreasing trend to 16–17% in 2020. The next species in terms of share in the sward, from 18 to 24% in subsequent years, was *Poa pratense*. Other grass species in this group included *Lolium perenne* (6–10%), *Festuca pratensis* (3–7%), and *Phleum pratense* (1–5%). Other grasses on both these sites constituted 20–33%. Among the overseeded legume plants, there was a clear increase in *Trifolium pratense* from 3 to 10%, and *Lotus corniculatus* from 1 to 2%. Special of herbs and weeds were the same as at site 0 and the previous two sites.

In subsequent years, the progressive changes in the sward species composition on individual sites resulted in slight alteration of its utility value. For site 0, the value was at the level of 63–67 Uvn. Regardless of the method and timing, the renovation of this meadow significantly increased the share of sown species, improving the utility value of the sward at 74–80 FV.

Experiment II in Racibory. The species composition of the meadow sward in Racibory (Tab. S1) at site 0, we established the presence of native grass species sown on the sites under renovation. In the first year of the study (2017), *Dactylis glomerata* accounted for the largest share in this group of 12%. This share later decreased to 7% in 2020. Another species, *Phleum pratense*, had a 10% share in the first year, which then dropped significantly to 2% in the following year. *Festuca pratensis* and *Lolium perenne* maintained their share of around 5% with slight fluctuations within one or two percent in subsequent years. *Poa pratense* had a 7% share in the first year, increasing to 9% in the third and fourth years. Other grasses on this site (i.e. other than overseeded) included *Festuca arundinacea*, *F. rubra*, *Agrostis gigantea*, *Elymus repens*, *Bromus hordeaceus*, and *Poa trivialis*. The share of these species in the sward decreased from 58 to 47% in subsequent years. In the legume plants group, *Trifolium pratense* accounted for 1% of the sward from the second year onwards, and there was a clear increase in the share of *Trifolium repens*. from the second year onwards. In the first year, the group of weeds on this site included *Artemisia vulgaris*, *Stellaria media*, *Veronica hederifolia*, and *Rumex crispus*, with their total share of 6%. In subsequent years, such species as *Glechoma hederacea*, *Stellaria media*, *Ranunculus repens*, *Taraxacum officinale*, and *Veronica hederifolia* increased their share, with the total share in the sward of up to 14% in 2020.

The species composition of native and sown grasses in the sward on both sites with strip-till overseeding in summer 2016 (STU/Sm) and spring 2017 (STU/Sp) was richer with *Festulolium* (2%) and *Lolium hybridicum* (3–12%). The share of native and sown species was significantly higher compared to site 0 on both sites. It was independent from overseeding timing and showed little variation between these sites. Among the sown grass species, all of them showed an increase in their share in the sward, with the largest increase in *Dactylis glomerata* (14–17%) and *Poa pratense* (11–21%) in the first and subsequent years. In the first year of the study, the share of *Lolium perenne* increased to 10% on both sites, showing a slight decrease in subsequent years. In the second and subsequent years, a slight increase in the share of *Phleum pratense* and *Festuca pratensis* was noted. In the group of other grasses, the same species as at site 0 were present, showing a gradual decrease in their share in the sward in subsequent years until 2020. At both sites, the group of legume plants was represented by two sown species: *Trifolium pratense* and *Lotus corniculatus*. In 2017, *Trifolium pratense* accounted for 15–16% of the sward, increasing to 22–25% in 2018, and then significantly decreasing in the next two years to 12–14%. *Lotus corniculatus* at site STU/Sm accounted for 1% in the first and subsequent years, while at site STU/Sp, its share in the sward increased slightly to 2% in 2019 and 2020. The group of herbs and weeds on these sites, similarly to site 0, was represented by the same species and *Stellaria media*, *Achillea millefolium*, and *Capsella bursa-pastoris*, with a total share of 3–7% in the first and second year, increasing to 10–12% in the following years.

In summer 2016 (VU/Sm) and spring 2017 (VU/Sp), the species composition of native and overseeded grasses in the sward at sites after disc seeder overseeding was also richer with the two new species: *Festulolium* and *Lolium hybridicum*. The share of these species was respectively 1 and 5% in the first and second year, showing a decreasing trend in subsequent years. Species such as *Festuca pratensis* and *Dactylis glomerata* did not show an increase in their share in the sward especially in the first year after overseeding. A clear increase of several percent in the share in both the first and subsequent years was shown by *Lolium perenne* and *Phleum pratense* from the second year on the VU/Sm site, and in subsequent years after spring overseeding (VU/Sp). The increase in the proportion of *Poa pratensis* in the sward in the first year and in subsequent years also indicates a clear overseeding effect. The significantly lower proportion of other (i.e. not overseeding) grass species in the sward on these sites confirms the beneficial effect of overseeding. In the group of legume species, a significant share of *Trifolium pratense* was recorded, but significantly less as in the previous method of overseeding, and only 1% of *Lotus corniculatus*. The group of herbs and weeds represented by the same species as in the previous sites showed their differentiated share which varied from 2% in the first year to 13% in the fourth year. This method of overseeding, regardless of its timing, showed smaller effects as the previous one (STU/Sm and STU/Sp). This is evident in the share of some inbred grasses and *Trifolium pratense*.

The progressive changes in the species composition of the sward in subsequent years on individual sites resulted in slight changes in its utility value, which at site 0 was at the less valuable level of 66–68 Uvn. The overseeding of this meadow, introducing new grass and legume species, regardless of the method and timing, increased the utility value of the sward by about 10–20 points, reaching 77–86 Fv.

Experiment III in Ranna. In Ranna, the species composition of the meadow sward (Tab. S1) at site 0 consisted of the same native species that were simultaneously overseeded at other sites: *Dactylis glomerata* and *Poa pratensis* (13–16%), *Lolium perenne* (3–7%), *Festuca pratensis* (3–4%), and *Phleum pratense* (1%) in the third and fourth years. In the group of other grasses on this site (i.e. not overseeded), the following species were distinguished: *Festuca arundinacea*, *F. rubra*, *Holcus lanatus*, *Phalaris arundinacea*, *Elymus repens*, *Arrhenatherum elatius*, *Bromus hordeaceus*, *Deschampsia caespitosa*, and *Alopecurus pratensis*. The share of these species in the sward decreased from 48 to 37% in subsequent years. In the legume plant group, *Trifolium repens* constituted 3–4% and *Vicia cracca* 1% in the first and second years. In the first and subsequent years, the group of weeds at this site included the following species: *Plantago lanceolata*, *Glechoma hederacea*, *Silene latifolia*, *Stellaria media*, *Ranunculus repens*, *Achillea millefolium*, *Taraxacum officinale*, *Cirsium arvense*, *Galium aparine*, and *Capsella bursa-pastoris*, with a total share of 9% in the first year, increasing to 19% in 2020.

After overseeding using the strip-till method in summer 2016 (STU/Sm) and spring 2017 (STU/Sp), the species composition of grasses in the sward at these sites was richer by two species: *Festulolium* and *Lolium hybridicum*. The share of native and sown species on both sites, regardless of the overseeding timing, showed a slight increase. Among the sown grass species, all showed an increase in their share in the sward, with the largest increase due to overseeding observed in *Poa pratense* and *Dactylis glomerata*. At both sites, *Festuca pratensis* had a significant share in the sward from 8 to 16% in subsequent years. *Lolium perenne* had a smaller share (3–9%) and *Lolium hybridicum* showed a decreasing trend from 5 to even 1% at one of the sites. Among the re grass species, *Phleum pratense* showed the smallest share in the sward (1–2%).

The group of legume plants on both sites was mainly represented by two overseeded species, *Trifolium pratense* and *Lotus corniculatus*, and occasionally *Vicia craca*. In 2017, *Trifolium pratense* accounted for 8–9% in the sward with a slight increase in its share to 10–11% in the following 2018 and a large decrease to 2–3% in two subsequent years. At the STU/Sm site, *Lotus corniculatus* accounted for 1 to 2% in the first and second years, and only 1% in the third and fourth years as at the STU/Sp site. The weed group at these sites, as in variant 0, was represented by the majority of the same species and the total share of these species, showing an increasing trend, ranged from 3 to 8% in subsequent years.

In summer 2016 (VU/Sm) and in spring 2017 (VU/Sp), the species composition of the group comprising native and overseeded grasses in the sward at the sites where the disc overseeding was richer with two new species, i.e. *Festulolium* and *Lolium hybridicum*. At both sites, the share of these species ranged from 1 to 3%, showing a decreasing trend in subsequent years. The group of native and overseeded grass species at both sites was dominated by *Dactylis glomerata* (25–26%) in the first year, with a slight downward trend to 24 and 23% in 2020. In subsequent years, the next most populous species in the sward was *Poa pratense* (18–20%). Other grass species in this group included *Festuca pratensis* (6–15%), *Lolium perenne* (3–8%), and *Phleum pratense* (1–2%) from the second to fourth year. At both sites, other grass species accounted for 22 to 33%. They have much smaller share in the sward compared to site 0. In the group of overseeded legume plants, a significantly lower share of both *Trifolium pratense* and *Lotus corniculatus* was noted. The share of *Trifolium pratense* in the sward was 5 to 6% in the first year, with a 2% increase in the second year and a significant decrease to 1–2% in the third and fourth years, whereas *Lotus corniculatus* did not exceed 1%. Herbs and weeds were represented by the same species as at Site 0 and at the two other sites.

In subsequent years, at site 0, progressive changes in the species composition of the sward deteriorated the usable value with a downward trend of 69 to 67 Uvn. The usable value of the sward on individual sites clearly increased by 10 to 20 points in the first year after overseeding, undergoing a decrease to 74–79 Fv in subsequent years.

Summarising, the increase in the usable value of the sward at individual sites was largely due to the increasing share of legume plants. Following a 1% increase in their share in the sward, legume plants contributed 3 kg·ha^{-1} of nitrogen, thus allowing to reduce fertilisation with this element.

DRY MATTER YIELDS

In 2017, in experiment I (Tab. 4), dry matter yields from three cuts at individual sites showed little variation, ranging from 10.51 to 11.00 t·ha^{-1}, within the same group. Due to unfavourable pluvial and thermal conditions in 2018, yields from two cuts ranged from 4.31 to 5.42 t·ha^{-1} at individual sites within the group a. In 2019, more favourable spring pluvial and thermal conditions allowed for significantly higher yields of the first cut at 7.20 t·ha^{-1} at site 0, with an increasing trend at sites STU/Sm, VU/Sm, and VU/Sp, within the same homogeneous group ab. A significant increase in yields to 8.70 t·ha^{-1} was observed at STU/Sp. Extremely unfavourable pluvial and thermal conditions in the further part of the season inhibited the regrowth of the sward and the yield with subsequent cuts. Much more favourable pluvial and thermal conditions in 2020 allowed for the harvest of three cuts, with yields ranging from 9.1 to 11.0 t·ha^{-1}, with a clearly increasing trend at site STU/Sm and a significant increase to 11.0 t·ha^{-1} at STU/Sp. Smaller increasing yields were noted on VU/Sm and VU/Sp sites.

In 2017, in experiment II (Tab. 4), dry matter yields from four cuts showed significant variation, ranging from 8.70 to 11.40 t·ha^{-1} at individual sites. The lowest yield was obtained at site 0, with an increasing trend at VU/SP, within group a, and STU/Sp, within the homogeneous group ab. A significant increase in yields compared to site 0 was observed at sites VU/Sm and STU/Sm, with both overseeding methods. Despite less favourable pluvial and thermal conditions in 2018, yields from four cuts ranged from 6.01 to 8.22 t·ha^{-1} at individual sites. The lowest yield was obtained at site VU/Sp, with a slightly increasing trend at STU/Sp and 0. A significant increase in yields was observed at sites STU/Sm and VU/Sm. In 2019, three cuts were harvested in this experiment, with yields ranging from 5.90 t·ha^{-1} at site VU/Sm, with a slightly increasing trend at 0 and VU/SP, within group a. Within homogeneous group ab, a clearly increasing yields to 7.10 t·ha^{-1} was observed at site STU/Sm. A significant increase in yields was observed at site STU/Sp. In the last year of the study (2020), under favourable pluvial and thermal conditions, most sites, regardless of the overseeding method and timing, showed an increasing trend in yields compared to 0, with a significant increase observed at VU/Sm.

In 2017, in experiment III (Tab. 4), dry matter yields from four cuts at individual sites showed little variation, ranging from 13.20 to 16.81 t·ha^{-1}, within the same group a. Unfavourable pluvial and thermal conditions in 2018 contributed to yields from two cuts ranging from 6.51 to 9.50 t·ha^{-1} at individual sites. The lowest yield was obtained at STU/Sm, with a clearly increasing trend at both sites overseeded with the disc seeder (VU/SP and VU/Sm). Extremely unfavourable pluvial and thermal conditions in 2019 delayed the first cut, with yields ranging from 6.30 t·ha^{-1} at site 0, with a clearly increasing trend at subsequent sites within group a to 8.01 t·ha^{-1} at VU/SP. In the last year of the study

Table 4. Annual yields of dry matter (Mg·ha^{-1}) in the experiments in the years 2017–2020

Experiment	Years	Number of swaths	Object				
			0	STU/Sm	STU/Sp	VU/Sm	VU/Sp
I	2017	I, II, III	10.6a	10.5a	10.5a	11.0a	10.8a
	2018	I, II, III	4.6a	5.3a	5.4a	4.5a	4.3a
	2019	I, II, III	7.2a	8.0ab	8.7b	8.2ab	8.4ab
	2020	I, II, III	9.1a	9.8ab	11.0b	9.6a	9.7a
			7.9a	8.4a	8.9a	8.3a	8.3a
II	2017	I, II, III, IV	8.7a	11.4b	10.0ab	11.1b	9.7a
	2018	I, II, III, IV	6.5a	7.8b	6.3a	8.2b	6.0a
	2019	I, II, III	6.0a	7.1ab	7.9b	5.9a	6.3a
	2020	I, II, III	8.2a	9.4ab	9.1ab	9.9b	9.1ab
			7.4a	8.9a	8.3a	8.8a	7.8a
III	2017	I, II, III, IV	13.2a	15.2a	14.4a	14.9a	16.8a
	2018	I, II	9.5b	6.5a	9.0b	8.0ab	8.0ab
	2019	I	6.3a	7.5a	7.8a	7.3a	8.0a
	2020	I, II, III	9.7a	11.0ab	10.5a	11.5b	10.1a
			9.7a	10.1a	10.4a	10.4a	10.7a

Explanations: O = control object, STU/Sm = strip till unit used on summer time, STU/Sp = strip till unit used on spring time, VU/Sm = Vredo unit used on summer time, VU/Sp = Vredo unit used on spring time, Uvn = utility value numbers; a, b, ab = homological groups.
Source: own study.

(2020), slightly more favourable pluvial and thermal conditions allowed for three cuts, with the lowest yield of 9.7 t·ha^{-1} at site 0, and an increasing trend at STU/Sp and VU/Sp. A clearly increasing trend was noted at STU/Sm and a significant increase at VU/Sm.

TOTAL PROTEIN AND SIMPLE SUGAR CONTENT IN DRY MATTER

In 2017, in the experiment I (Tab. 5), the average annual protein content at site 0 was 11.92%, with a significant increase to over 14% observed at both STU/Sm and VU/Sm sites. A clearly increasing trend in protein content was noted at site VU/Sp within group ab, and a further significant increase to 15.43% at STU/Sm. In 2018, protein content was significantly higher at all sites, ranging from 15.25 to 16.69%, with no significant differences. In 2019, the lowest protein content of 13.56% was observed at site STU/Sm, with a clearly increasing trend in protein content at STU/Sp, VU/Sp, and 0, within homogeneous group ab. A significant increase in protein content in dry matter to 15.11% was observed at site VU/Sm. In 2020, protein content in dry matter yields from individual sites ranged from 14.24 to 15.63%, with no significant differences.

In 2017, in the experiment II, protein content in dry matter yields was 12.03% at site 0, with a significant increase to 14.52% at VU/SP and a further increasing trend at STU/Sm and STU/Sp. A significant increase in protein content to 16.67% was observed at site VU/Sm. In 2018, similarly to the previous year, protein content at site 0 remained the same, with a significant increase to over 14.5% observed at STU/Sm and VU/SP. A further increasing trend in protein content was noted at site STU/Sp, with a significant increase to 16.67% at VU/Sm. The lowest protein

Table 5. Percentage of total protein in dry matter yields in the experiments in the years 2017–2020

Experi-ment	Years	Object				
		0	STU/Sm	STU/Sp	VU/Sm	VU/Sp
I	2017	11.92a	14.20b	15.43c	14.17b	15.21bc
	2018	15.44a	15.25a	16.69a	15.97a	15.43a
	2019	14.58ab	13.56a	14.44ab	15.11b	14.56ab
	2020	14.24a	14.86a	14.53a	15.02a	15.63a
II	2017	12.03a	14.67bc	15.44bc	16.67c	14.52b
	2018	12.03a	14.67b	15.45bc	16.67c	14.52b
	2019	13.75a	14.65ab	16.17b	15.21ab	15.46ab
	2020	12.50a	13.30a	13.13a	13.60a	13.76a
III	2017	15.63ab	16.18b	16.83b	14.69a	16.58b
	2018	14.04a	15.36ab	16.78b	14.02a	16.30b
	2019	14.39a	14.62a	15.48a	14.83a	16.50b
	2020	13.93a	15.12b	15.22b	14.46ab	15.12b

Explanations as in Tab. 4.
Source: own study.

content in 2019 (13.75%) was observed at site 0, with a clearly increasing trend at STU/Sm, VU/Sm, and VU/Sp to 15.46%. A further significant increase in protein content to 16.17% in dry matter was observed at site STU/Sp. In 2020, protein content in dry matter yields was significantly lower than in previous years at all sites, with the lowest content of 12.50% at site 0, and a slightly increasing trend at subsequent sites, reaching 13.76% at VU/Sp.

In 2017, in the experiment III, the average protein content in dry matter yields was the lowest at 14.69% at site VU/Sm, with a clearly increasing trend to 15.63% at site 0. A significant increase in protein content to 16.83% was observed at sites STU/Sm, VU/Sp, and STU/Sp. In 2018, protein content was lower at all sites than in the previous year, with the lowest content of around 14.0% at VU/Sm and 0. A clearly increasing trend in protein content in dry matter yields to 15.36% was observed at site STU/Sm, with a significant increase to around 16.5% at STU/Sp and VU/SP. In 2019, the average annual protein content in yields at most sites ranged from 14.39 to 15.48%, with no significant changes and a significant increase to 16.50% observed at VU/Sp. In 2020, protein content in dry matter yields at most sites was lower than in previous years, with the lowest content of 13.93% at site 0. A clearly increasing trend in protein content to 14.46% was observed at site VU/Sm, with a significant increase to 15.22% at STU/Sm, VU/Sp, and STU/Sp.

In 2017, in experiment I, the average annual simple sugar content in dry matter (Tab. 6) showed little variation at all sites, ranging from 5.55% at VU/Sm to 6.71% at STU/Sm, within the same group a. In 2018, similarly to the previous year, simple sugar content in dry matter yields showed low levels, ranging from 4.78 to 6.74%, with no significant differences between sites. In 2019, simple sugar content was significantly higher, ranging from 7.76 to 9.94% at individual sites, with no significant differences. In 2020, simple sugar content in dry matter yields showed lower variation, ranging from 8.00 to 9.01%.

Table 6. Percentage of total sugar in dry matter yields in the experiments in the years 2017–2020

Experiment	Years	Object				
		0	STU/Sm	STU/Sp	VU/Sm	VU/Sp
I	2017	6.10a	6.71a	5.72a	5.55a	5.76a
	2018	5.65a	5.94a	6.74a	4.78a	6.74a
	2019	8.68a	9.20a	9.25a	7.76a	9.94a
	2020	8.24a	8.00a	8.60a	9.01a	8.00a
II	2017	11.25b	10.36ab	9.03a	9.02a	9.96ab
	2018	9.66b	7.87a	8.13a	7.82a	8.45ab
	2019	9.36a	8.93a	9.03a	9.11a	8.98a
	2020	7.50a	9.09a	8.63a	8.71a	9.22a
III	2017	7.36a	7.24a	8.08a	8.08a	7.32a
	2018	5.73a	5.85a	5.56a	4.95a	4.68a
	2019	5.67ab	6.54b	6.03ab	5.18ab	4.08a
	2020	6.45a	6.75ab	7.79b	7.25ab	7.01ab

Explanations as in Tab. 4.
Source: own study.

In 2017, in experiment II, the average annual simple sugar content in dry matter yields (Tab. 6) was the lowest (9.02%) at VU/Sm, similar to STU/Sp, with a clear increasing trend at VU/Sp and STU/Sm, within the same homogeneous group ab. A significantly higher simple sugar content in dry matter was observed at site 0. In 2018, simple sugar content in dry matter was similar at all sites, ranging from 7.82 to 8.13% at VU/Sm, STU/Sm, and STU/Sp. An increasing trend in simple sugar content was noted at site VU/Sp, with a significant increase to 9.66% at site 0. In 2019, simple sugar content in dry matter at most sites was significantly higher than in the previous year, with no significant differences. In 2020, simple sugar content in dry matter ranged from 7.50% at site 0, with a slightly increasing trend at other sites, reaching 9.22%, with no significant differences.

In 2017, in experiment III, simple sugar content in dry matter (Tab. 6) showed no significant differences between all sites, ranging from 7.24% at STU/Sm to 8.08% at STU/Sp, within the same group a. Significantly lower simple sugar content was observed in dry matter yields in 2018, with no significant differences between individual sites, ranging from 4.68% at VU/Sp to 5.85% at STU/Sm. In 2019, simple sugar content in dry matter in this experiment showed significantly greater variation, ranging from 4.08% at site VU/Sp to 6.54% at STU/Sm. A clearly increasing trend in simple sugar content was observed at VU/Sm, STU/Sp, and a significant increase at STU/Sm. In 2020, the lowest simple sugar content in dry matter was 6.45% at site 0, with a clearly increasing trend at STU/Sm, VU/Sp, and VU/Sm to 7.25%, within the same homogeneous group ab. A significant increase in simple sugar content to 7.79% was observed at site STU/Sp.

PROTEIN AND SIMPLE SUGAR YIELDS

Since dry matter yields, and the content of total protein and simple sugars show little variation between different overseeding periods and methods, it is possible to present their average values. Average protein yields over the four-year period (Fig. 1) in experiment I ranged from about 1.08 $Mg \cdot ha^{-1}$ at site 0 to over 1.25 $Mg \cdot ha^{-1}$ on both overseeded sites, showing an increase of about 0.20 $Mg \cdot ha^{-1}$. In experiment II, at site 0, average protein yield over the period was 0.92 $Mg \cdot ha^{-1}$, with an increase to about 1.23 $Mg \cdot ha^{-1}$ for both overseeding methods, indicating an increase of 0.31 $Mg \cdot ha^{-1}$. The highest average protein yield of 1.38 $Mg \cdot ha^{-1}$ was obtained in experiment III, with a significantly higher level of fertilisation. However, after overseeding with both methods an increase was 0.20 $Mg \cdot ha^{-1}$.

In experiment I, average simple sugar yields over the period (Fig. 2) were the lowest at all sites. They ranged from 0.57 $Mg \cdot ha^{-1}$ at site 0 to 0.61 $Mg \cdot ha^{-1}$ at VU/Sm + VU/Sp and 0.66 $Mg \cdot ha^{-1}$ at STU/Sm + STU/Sp, showing an increase of 0.09 $Mg \cdot ha^{-1}$.

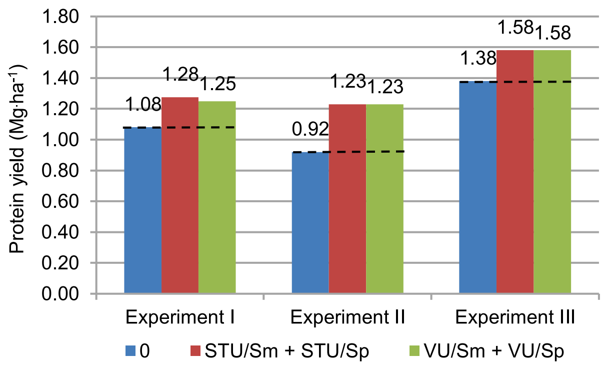

Fig. 1. Average annual protein yield at individual sites during experiments conducted in experiment I, II and III; O = control object; STU/Sm = strip till unit used on summer time; STU/Sp – strip till unit used on spring time; VU/Sm – Vredo unit used on summer time; VU/Sp – Vredo unit used on spring time; source: own study

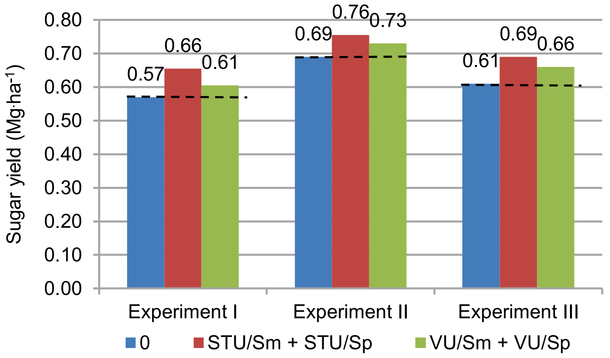

Fig. 2. Average annual simple sugar yields from individual sites during experiments in experiment I, II and III; STU/Sm, STU/Sp, VU/Sm, VU/Sp as in Fig. 1; source: own study

Significantly higher simple sugar yields at all sites were obtained in experiment II. They ranged from 0.69 Mg·ha^{-1} at site 0 to 0.76 Mg·ha^{-1} at STU/Sm + STU/Sp and 0.73 Mg·ha^{-1} at VU/Sm + VU/Sp, showing increases of 0.07 and 0.04 Mg·ha^{-1} after overseeding. In experiment III, simple sugar yields were significantly lower than in the previous experiment. They ranged from 0.61 Mg·ha^{-1} at site 0 to 0.66 Mg·ha^{-1} at VU/Sm + VU/Sp and 0.690 Mg·ha^{-1} at STU/Sm + STU/Sp, indicating increases of 0.05 to 0.08 Mg·ha^{-1} after overseeding.

DISCUSION

The effects of overseeding depend on the status of vegetation determined by many abiotic, biotic, and anthropogenic factors (Kozłowski, 1998; Mikołajczak, 1998). The growth and development of species introduced by overseeding, as specified in studies by Janicka (2004; 2012) and Barszczewski, Jankowska-Huflejt and Twardy (2015), depended on the competition for water and light among plants growing from the primary sward. This influence was eliminated in the experiments by overseeding. The effects of overseeding, as in the study by, depended on meteorological conditions. Under varied meteorological and habitat conditions in Poland, the studies confirmed the results obtained by many authors (Skopiec, Kowalczyk and Kamiński, 1991; Baryła, 1996; Janicka, 2004; Łyszczarz *et al*., 2010; Janicka, 2012; Barszczewski, Terlikowski and Wróbel, 2017) and indicated a significant enrichment of the sward with valuable species in the first year after overseeding both in spring and autumn. In the second and third year (2017, 2018), the effects of both overseeding methods, depended on meteorological conditions, especially when pluvial and thermal conditions were extremely unfavourable. This has also been shown by Bartmański and Mikołajczak (1995), Kitczak and Dobromilski (1995), Baryła and Kulik (2012). The water factor (extreme water shortage) was also important, as confirmed by research of Grzegorczyk (1998) and Barszczewski, Terlikowski and Wróbel (2017). In experiment II and III, with poorer brown soil formed from slightly loamy sand but more favourable pluvial and thermal conditions in the fourth year, better results were obtained with increased yields. This was achieved while maintaining a favourable proportion of grasses, but a marked reduction of legume plants in the sward. This helped to maintain a favourable usable value of the sward. Legume plant by increasing its participation in sward.

The positive effects of overseeding with intensive, short-lived varieties of grasses and legume plants in individual experiments under varying soil and meteorological conditions were expressed by enrichment of the species composition in the sward. The enrichment of the species composition in the sward within the permanent grasslands, especially with valuable species of grass and legume plants improved the site usable value, (Goliński and Golińska, 2008; Golińska and Goliński, 2023) notably with increased yields of dry matter, and total protein and simple sugars. A long with their increasing share in sward. This reduces the need of additional fertilisation and consequently financial benefits for farmers and the environment due to a reduced carbon footprint at the permanent grassland site (Barszczewski, Wróbel and Jankowska-Huflejt, 2011; Kakraliya *et al*., 2018).

The compared methods of overseeding showed little variation in dry matter yields, a slightly higher increase in the proportion of introduced grass species in the sward, but a markedly higher proportion of legume plants in the strip-till seeding technique. On all experiments was not observed influence of soil type on legume participation in the sward as it confirmed by Mikołajczak (1998), researches who emphasised the importance of technique in this method. According to the above, the strip-till seeding reduces competitiveness in the old sward and allows for better access of young seedlings to light and water. Regardless of the method used, under the conditions of drought-stricken hardwood meadows on rich soils comprising light and medium clay, as in experiment II and III, the direct seeding method has a significantly lower risk of failure than on sandy soils in experiment I even under unfavourable pluvial and thermal conditions.

CONCLUSIONS

1. The renovation of permanent grasslands by overseeding with grass mixtures containing tetraploid varieties and about 30% of legume plants was an effective treatment. The treatment clearly improved the species composition of the sward, its functional value, and yields of dry matter, total protein, and monosaccharides in all experiments despite unfavourable pluvial and thermal conditions in I and III in 2017 and 2018.
2. Despite the various share of legume plants in the sward during individual experiments, their growth was noted after overseeding. This translated into reduced need for nitrogen based fertilisation. This allows to reduce fertilisation and at the same time increase yields of proteins from 200 to 300 kg·ha^{-1}. The beneficial effects of this treatment should be assessed from the economic and environmental points of view.
3. A significantly higher proportion of legume plants and grass species at overseeded sites indicated the higher efficiency of the strip-till seeding method under varying pluvial, thermal, and soil conditions.
4. The compared dates of overseeding at both experiments in I and III did not show clear differences in species composition and yields. However, in most cases there was a noticeable increase in the yield after summer harvesting in II.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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