agriculture

MDPI

Article

The Impact of the Renovation of Grassland on the Development of Segetal Weeds in Organic Farming

Eliza Gaweł [1,*], Mieczysław Grzelak [2], Bogusława Waliszewska [3] and Magdalena Janyszek-Sołtysiak [4]

1 Department of Forage Crop Production, Institute of Soil Science and Plant Cultivation—State Research Institute, Czartoryskich 8 Str., 24-100 Puławy, Poland
2 Department of Grassland and Natural Landscope, Poznań University of Life Science, Dojazd 11 Str., 60-656 Poznań, Poland; mieczyslaw.grzelak@up.poznan.pl
3 Department of Chemical Wood Technology, Poznań University of Life Science, Wojska Polskiego 38/42, 60-637 Poznań, Poland; boguslawa.waliszewska@up.poznan.pl
4 Department of Botany, Poznan University of Life Science, Wojska Polskiego 71 C, 60-625 Poznań, Poland; magdalena.janyszek-soltysiak@up.poznan.pl
* Correspondence: eliza.gawel@iung.pulawy.pl; Tel.: +48-81-478-6794

Abstract: The intensive use or discontinuation of the use of swards can compromise biodiversity, yields, and feed quality; thus, leading to the degradation of permanent grasslands. Various methods of renovation are employed to restore the usability of degraded swards. In the years 2013–2016, a monofactorial field experiment was carried out on the Experimental Farm in Grabów (province of Mazowieckie, Poland). The experiment involved swards being reseeded after ploughing (P) and after disking with a compact harrow (H), with a non-renovated sward as the control treatment. The plots under renovation were reseeded with a lucerne–grass mixture. Both seedbed preparation methods for the renewed sward, ploughing (P) or shallow disking to a depth of 5 cm (H), were found to be effective for increasing sward yields, restricting weed growth, and reducing the number of weeds in the sward. The ploughing-based renovation method (P) had a strongly restrictive effect on biodiversity, as expressed by the *H′* function value vis-à-vis the harrow method (H) and the non-renewed control (NR). Dicotyledonous species accounted for 92.3% of the weed population in the studied treatments. Of these, *Taraxacum officinale*, *Achillea milefolium*, *Capsella bursa-pastoris*, and *Plantago maior* occurred in the highest numbers.

Keywords: grassland renovation; ploughing; harrow; biomass index; diversity (*H′*) and dominance index (*SI*); segetal weeds

check for updates

Citation: Gaweł, E.; Grzelak, M.; Waliszewska, B.; Janyszek-Sołtysiak, M. The Impact of the Renovation of Grassland on the Development of Segetal Weeds in Organic Farming. *Agriculture* **2022**, *12*, 738. https://doi.org/10.3390/agriculture12050738

Academic Editor: Marit Jørgensen

Received: 27 April 2022
Accepted: 19 May 2022
Published: 23 May 2022

1. Introduction

Currently, 22% of Europe's total area comprises natural or semi-natural grasslands [1]. In recent years, pasture and meadow areas have been shrinking throughout the continent. This is especially true of the industrialized countries of western and central Europe, where a rapid development of intensive farming, supported by numerous subsidies has been taking place. Agriculture in eastern Europe is developing under the conditions of modest financial coverage, inadequate machinery and equipment, or even inadequate skills of farm operators. All of these things contribute to the discontinuation or suspension of agricultural activities on grasslands. Once taken out of cultivation, abandoned grasslands undergo degradation [2,3].

The issue of grassland deterioration is common knowledge. In Poland, due to various causes, more than half of grasslands are subject to degradation and are in need of renovation [4,5].

Generally, the main reasons to renovate a meadow are substantially depressed yields, a general decline in valuable forage grasses and legumes, the deterioration of species richness in a sward, and the development of weeds in the sward, as well as the planned intensification of grassland use or restoration of abandoned grassland to cultivation [4,6–10].

Weed infestation of grassland swards is referred to as when weeds occur in numbers that directly or indirectly lead to economic losses, due to reduced quality or yield level, and increased labor intensity or energy consumption of production. Döring et al. [11] spoke of a higher tolerance to weeds on grassland than on arable land if they occur in moderate quantities. The agricultural use of grasslands and weather conditions also affect the degree of weed infestation and the proportion between herbage yield and weed weight of a sward. Sward biomass and weed weight are negatively correlated and, immediately after sward renovation, annual weeds are more numerous than perennials [11]. Dangerous, invasive weeds should not cover more than 5% of a sward's area [12]. Absolute weeds are obligatorily controlled on grasslands [13]. On the contrary, relative weeds in a sward play the role of herbs, enriching the botanical composition, increasing the biodiversity of the sward, and providing animals with various nutrients, mainly minerals and active substances, thus supporting the animal organism [11]. In grasslands, it is advisable to observe the weed infestation dynamics, because the number of weed and plant species may undergo unpredictable fluctuations in certain years [12], and it is known that excessive weed infestation limits the productivity of crops in a sward [11].

The main objective of grassland renewal is to improve the yield and quality of fodder. After a renovation was performed, Martin et al. [14] obtained a 2–4-fold increase in yields from the renewed sward. However, the biodiversity, as expressed by Simpson's dominance index (*SI*), was substantially lower than that prior to sward renovation.

The most popular method involves ploughing and full tillage being applied to the soil, followed by reseeding with a legume–grass seed blend [4]. The major disadvantage of this approach is, among other things, the fast development of weeds from the soil seed bank. Weeds compete with slow-growing legume and grass seedlings and restrict their development in renewed swards [15]. In grassland renovation, simplified tillage is also used, which involves, for example, disturbing the upper soil layer to a depth of 5 cm with a disk harrow, band sowing, or direct seeding; with all of these approaches being less harmful to the environment than ploughing and full tillage [16–18]. Another drawback of some reduced tillage practices, such as disturbance of the topsoil with a compact harrow, is the rapid recovery of some large-root weeds that have not been totally destroyed [15]. Along with legume–grass mixtures, different herb plants are used to reseed swards. These herbs exert a positive effect on the digestive tract of animals, destroy intestine parasites, and increase sward yields. Some of them, such as chicory, a plant rich in nutritive minerals, also boost the milk productivity of cows [17,19,20].

Weeds infesting a given tract of grassland are effectively kept down by proper management, adequate care of swards, and uniform distribution of particular species in said swards, be it even in a two-component mixture, whereas intensive use and overgrazing favor the prevalence of grass in swards [21]. A sward's species composition and its ability to compete against weeds are also of great importance in preventing excessive weed growth. *Festuca arundinacea* (Schreb.) has been shown to suppress weeds to a greater extent than *Bromus inermis* (Leyss.) [21]. A multispecific sward is regarded as being more palatable to animals than a monospecific one [22].

No harvesting, low-intensity management, and excessive grazing all negatively affect swards, by reducing the biodiversity and number of plant species [7,21]. The percentage share of weeds in a sward can be kept down by, among other approaches, biological methods; applying bioherbicides, such as fungal preparations targeted at a defined weed species [23,24] or bioagents that contain natural pathogens to certain weed species [25].

To date, the majority of studies dealing with the effect of the tillage system on weed infestation have concerned cereals or legumes [26,27]. Few of them have described the biodiversity of grasslands, where weeds pose a major threat to cultivated species. The use of herbicides is banned under the organic regime; this is a considerable impediment to weed control, which, in the renovation year, is reduced to one or two cuts being applied to a sward [28]. Furthermore, plough renovation has an adverse effect on the environment [18]. Owing to this, there is a need to search for less-invasive tillage methods, such as surface cultivation with a compact disk harrow, band sowing, and direct seeding. Once the renovation is completed, the degree to which a meadow is infested with weeds and the level of competition from weeds are crucial to the yielding potential of a sward and in making decisions about how soon it will likely have to be renovated again [4,6,29].

The research hypothesis assumes an increase in sward productivity and a decrease in weight and number of weeds as a result of sward renewal.

The objective of this study, conducted under organic farming management, was to find out whether, and to what extent, two methods of grassland renewal would affect the performance of a sward, including the specific composition of the yield and the weight of the weeds, Shannon–Wiener's diversity index (*H'*), and Simpson's dominance index (*SI*) vis-à-vis those indicators in a non-renovated sward (NR). The study was also supposed to furnish information on which of the two grassland renewal methods would be more beneficial to farming practices in terms of sward yields and weed suppression.

2. Materials and Methods

2.1. Field Experiment and Cultivation Management

The study on weed infestation of a renewed sward of organically managed grassland in a moderate continental climate zone was conducted on the Experimental Farm in Grabów, Mazowieckie province, Poland (51°21′ N; 21°40 E) in the years 2013–2016. The experiment was set up on a luvisol developed from light loam (Umbrisols and Phaeozems according to the FAO-WEB soil classification system of 2014). The characteristics of this soil are shown in Table 1. One-factor experiment treatments were arranged in a randomized block design. The experimental factor comprised two renovation methods that involved ploughing (P) or harrowing (H), plus a non-renovated sward used as the control treatment (NR). In May 2013, in accordance with the experimental layout, the plots under a full tillage regime (treatment P) were ploughed to a depth of 30 cm, while in those assigned to treatment H, the topsoil was disked to a depth of 5 cm with a compact harrow, and the control treatment (no renovation, NR) was laid out on a degraded tract of grassland that received no tillage practices. The NR treatment was characterized by a low, poorly developed grass sward that contained no legumes and a considerable number of weeds.

Table 1. Soil characteristics.

Content of Soil Fraction (%)			N mg kg^{-1}		Soil pH_{KCl}	Absorbable Form in Soil mg·(100 g)$^{-1}$			Total Calcium (%)	C_{org} (TOC) (%)
1–0.1 mm	0.1–0.02 mm	<0.02 mm	N–NH_4	N–NO_3		P_2O_5	K_2O	Mg		
56	24	20	6.00	16.90	6.52	13.06	7.25	14.83	0.35	2.05

On 20 June 2013, 30 kg·ha^{-1} of the MFL legume–grass commercial seed blend manufactured by Agriland seed company was sown [30]. The seeded mixture consisted of 30% lucerne, 40% festulolium, 20% perennial ryegrass, and 10% annual ryegrass, as converted to label rates in pure sowing. The area of a single plot was 100 m^2; the dry matter yield of the sward and weeds was determined in grams per square meter. In the seeding year (2013), weeds were removed twice by cutting when the sward reached a height of 30 cm (July and August). In October, the total experimental area was put to 2–3 days of grazing by cows.

Pre-plant fertilization was applied to the soil immediately prior to implementing tillage practices. Phosphorus was supplied at 90 kg·ha^{-1} of P_2O_5 as 30% ground rock phosphate, and potassium was given at a rate of 70 kg·ha^{-1} of K_2O as 50% potassium sulfate. In each utilization year, at the start of vegetation growth, 10 t·ha^{-1} of cattle manure was applied, together with phosphorus (90 kg·ha^{-1} of P_2O_5) and potassium (30 kg·ha^{-1} of P_2O_5). The sward was utilized under a rotational grazing hay production system. The first and third cut were most frequently used for haylage, while the second and fourth regrowth was grazed by 79–85 milk cows.

2.2. Analysis of the Weed Population

In each full utilization year, sward vegetation was analyzed for weed weight, overall biomass weight, weed species richness, and plant number. The weed-picking frame method was used for weed sampling. The impact of the renovation method of organically managed meadows on weed population was evaluated in three sward regrowths of each plot. On each plot, prior to harvest, the weeds were extracted from a frame with dimensions of 0.5×1 m, with four replications at each sampling site. After removing and counting all weeds, the herbage was cut from the area covered by the frame, its fresh weight was estimated, and it was subsequently dried at 60 °C. The weed nomenclature was adopted from the work of Mirek et al. [31].

The collected weeds were weighed and dried separately at a temperature of 60 °C. The degree of weed infestation in each regrowth was assessed by calculating the biomass index averaged over the years 2014–2016, according to the formula developed by Patriquin et al. [32]:

$$Biomass\ index = \frac{crop\ biomass \times 100}{weed\ biomass + crop\ biomass}, \tag{1}$$

2.3. Diversity Indicators

The species composition in the regrowth of grassland vegetation, as affected by different methods of renovation, was described using two indices: Shannon–Wiener's index (H') [33] and Simpson's dominance index (SI) [34]. The H' index describes biodiversity, and its value defines the probability that two individuals belong to two different species.

Shannon–Wiener's (H') and Simpson's (SI) indices were calculated according to the following formulas [33]:

$$H' = \Sigma pi \cdot ln \cdot pi \tag{2}$$

$$SI = \Sigma pi^2 \tag{3}$$

where

$pi = n/N$,
n—the number of individuals in species,
N—the total number of individuals in the area,
Ln—the natural log.

2.4. Weather Conditions

The weather conditions varied substantially over the years of the study (Table 2). In 2013, the experiment was sown under good weather conditions and, hence, the plant emergence was successful and growth and development proceeded normally. After the plants reached a height of ca. 30 cm, the weeds were destroyed twice by cutting the sward. In the subsequent months of the seeding year (July and August), the moisture conditions were unsuitable for the growth and development of the grassland reseeds under renovation.

Table 2. Weather condition data for the growing seasons of the study.

Specification	Month							Sum/Average III–IX
	III	IV	V	VI	VII	VIII	IX	
				2013				
Precipitation (mm)	41.1	29.9	112.0	116.3	20.8	11.6	63.9	395.6
Temperature (°C)	−2.1	8.3	15.3	18.6	19.7	19.2	11.8	15.1
				2014				
Precipitation (mm)	42.0	56.6	154.9	90.7	115.3	98.8	15.9	574.2
Temperature (°C)	6.3	9.9	13.5	15.2	20.4	17.9	14.4	13.9
				2015				
Precipitation (mm)	63.2	34.8	107.0	30.3	51.7	6.2	93.9	387.1
Temperature (°C)	5.0	8.1	12.7	16.9	19.7	22.1	15.0	14.2
				2016				
Precipitation (mm)	52.3	45.1	39.4	60.1	81.9	53.6	20.3	352.7
Temperature (°C)	3.9	9.2	14.9	18.7	19.2	18.1	15.7	14.2
Average long-term precipitation (mm)	30.0	41.0	57.0	71.0	84.0	75.0	50.0	408.0
Average long-term temperature (°C)	1.6	7.8	13.4	16.8	18.4	17.3	13.2	12.6

The replicated trial on the development of weeds after renovation of organically managed grassland was conducted in the years 2014–2016 under varied weather conditions (Table 2). In 2014, ca. 80% of the growing season precipitation was recorded in May, June, July, and August. In September of 2014, the amount of precipitation was one third of the long-term average for that month. Consequently, the growth and yield of the last sward regrowth in that growing season was negatively affected by the substantial shortage of rainfall. In the spring of 2015, optimum moisture and thermal conditions prevailed. Next, starting with July, a shortage of rainfall recurred, and in August, the recorded precipitation was only 6.2 mm. In the subsequent year (2016), a soil water deficit occurred as early as April and lasted until the end of the growing season. The year 2016 (third year after renovation) was characterized by the lowest sum of rainfall over the whole study period (352.7 mm) and accounted for only ca. 61% of the highest annual rainfall (574.2 mm), recorded in 2014. Despite significant sward thinning due to rainfall deficiency in 2015 and 2016, field collection of data on sward weedinees, biomass index, and diversity (*H′*) and dominance (*SI*) indices was continued, without attempts to reseed the sward.

2.5. Experimental Design and Statistical Analysis

In this paper, average values for the effect of two sward renovation methods applied to a grassland on herbage yield, weed weight, and biomass index are presented for the years 2014–2016. In each sward regrowth, data on dry matter yield and weed weight were evaluated statistically using monofactorial analysis of variance (ANOVA, Statistica v.10.0, Stat Soft Inc., Tulsa, OK, USA). Tukey's multiple comparison test (HSD) was used to compare the means for the renovation methods.

3. Results

Averaged over the years 2014–2016, the weed weight of the first sward regrowth was similar in all treatments; after plowing (P), after compact harrowing (H), and in non-renewed sward (NR) (Figure 1). In the second sward regrowth, weed mass on the site prepared by disking (H) was significantly greater than after plow tillage (P) (Figure 1). This said, the weed mass in both renovation-involving treatments was significantly lower than that in the non-renovated (NR) treatment (Figure 1). Likewise, in the third sward regrowth, the renewed swards (treatments P and H) showed a significantly lower weed infestation than the non-renovated sward (NR). In the third regrowth, an increase in weed weight over that in the first regrowth of 39.3 percentage points was observed (Figure 1). The increasing weight of weeds could testify to a continuing process of sward deterioration with the non-renovated treatment (NR) (Tables 3 and 4).

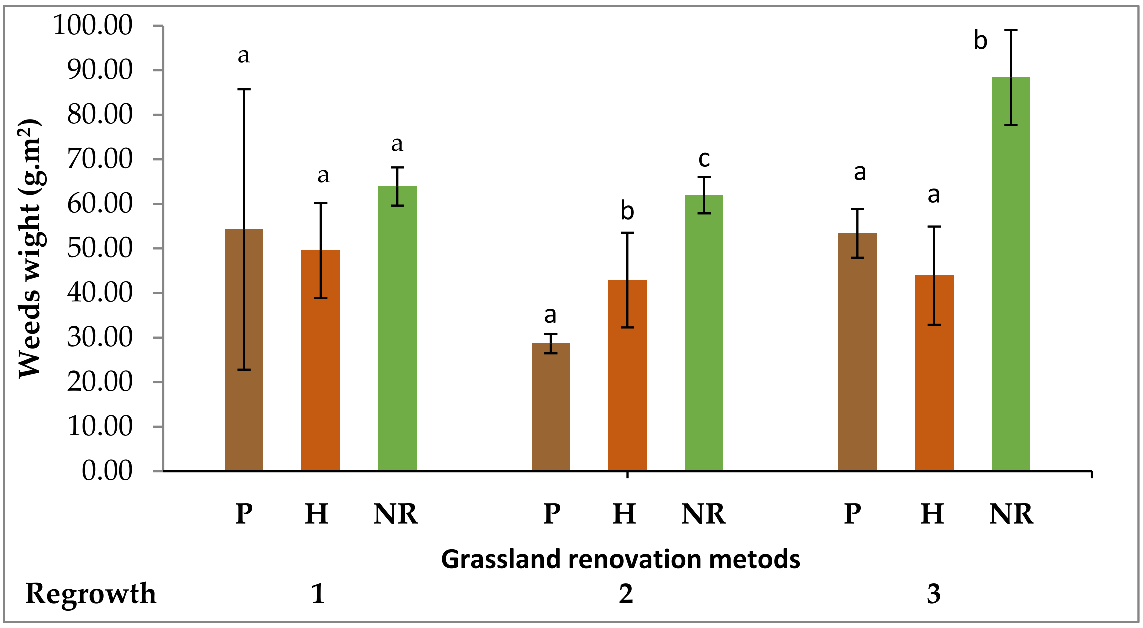

Figure 1. Three-year averages of weed weight by grassland renovation method and by regrowth. P—ploughing; H—harrowing; NR—non-renovated (control treatment). In regrowth, the same letter above a column means no significant difference between the means.

Table 3. ANOVA summary of the average dry weed weight for 2014–2016.

Methods Renovation	Regrowth		
	1	**2**	**3**
ANOVA summary			
F-ratio	0.58	6.24	6.19
p-Value	0.57	0.019	0.02
Standard error (SE)	9.56	6.69	9.4

Table 4. ANOVA summary of the average dry biomass weight by grassland for 2014–2016.

Methods Renovation	Regrowth		
	1	**2**	**3**
ANOVA summary			
F-ratio	7.22	5.3	4.63
p-Value	0.013	0.03	0.041
Standard error (SE)	37.7	16.92	13.34

In terms of the average values for the period 2014–2016, the highest dry matter yield of renewed sward was found in the first regrowth (Figure 2). Sward renovation caused a significant increase in the yield level compared to the degraded sward (NR). All regrowths benefited from sward renewal, both by harrow (H) and by plow (P), which is shown by the data in Figure 2. The non-renewed control treatment (NR) was conspicuous for its lowest dry matter yield, which was significantly lower than in the other treatments.

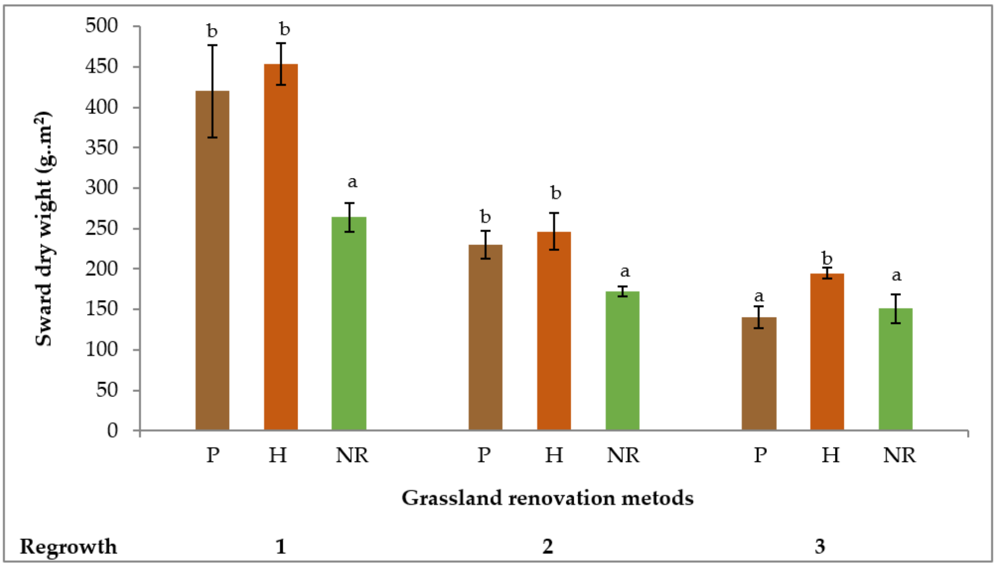

Figure 2. Three-year averages of dry biomass weight by grassland renovation method and by regrowth. P, ploughing; H, harrowing; NR, non-renovated (control treatment). In regrowth, the same letter above a column means no significant difference between the means.

Averaged across the years 2014–2016, sward renovation showed a significant impact on the biomass index used as indicator of weediness, when estimated on a regrowth-to-regrowth basis (Figure 3). In the first sward regrowth, sward renewal by topsoil disking (H) resulted in a significantly higher biomass index than that recorded for the non-renovated treatment (NR). The highest values of biomass index were found for the first regrowth, which indicates that weeds contributed little to the sward biomass in that period (Figure 1). On the contrary, the second and third regrowths of the swards renewed by ploughing (P) or by harrowing (H) stood out for their significantly higher biomass indices vis-à-vis the degraded, non-renewed sward (NR). In this study, the value of the biomass index was lowest in the third regrowth: 75.54% for the plough treatment (P); 82.31% for the disk harrow treatment (H), and 63.27% for the degraded, non-renewed treatment (NR) (Table 5 and Figure 3).

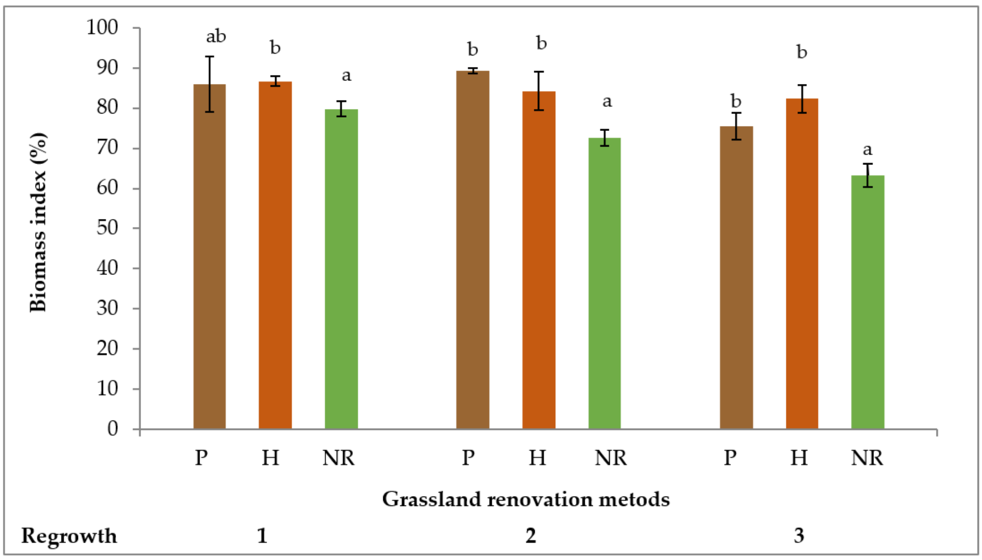

Figure 3. Three-year averages of biomass index (%) by grassland renovation method and by regrowth. P, ploughing; H, harrowing; NR, non-renovated (control treatment). The same letter above a column means no significant difference between the means.

Table 5. ANOVA summary of the average of biomass index for 2014–2016.

Methods Renovation	Regrowth		
	1	2	3
ANOVA summary			
F-ratio	3.22	8.41	9.008
p-Value	0.088	0.0087	0.0071
Standard error (SE)	2.092	2.96	3.21

In each of the sward regrowths, the lowest 2014–2016 averages of the biomass index were obtained for the degraded grassland: 79.84%, 72.61%, and 63.27% in the first, second, and third regrowths, respectively. These values testify to a fairly high weed infestation, especially in the third regrowth (Figure 3).

Averaged across the years 2014–2016, the data on the degree of weed infestation indicate that sward weediness (plants m^2) varied with the renovation method and over consecutive regrowths (Table 6). A total of 39 species were identified in the sward, including 18 herbs and 21 weeds (18 dicots and three monocots). Overall, dicot species accounted for 92.3% of the total weed population (Table 6).

Table 6. Occurrence rate of weed species in the sward by renovation method and by sward regrowth (plants m^2) averaged across the three years of study (2014–2016).

Weed Species	A/P	Plants per 1 m^{-2}								
		Regrowths of the Sward								
		1			2			3		
		P	H	NR	P	H	NR	P	H	NR
Herbs										
Taraxacum officinale Web. MP, PP	P	52.8	34.5	39.17	106.0	73.67	54.0	104.33	69.58	86.58
Glechoma hederacea L.	P	0.33	-	3.0	-	-	0.16	-	-	-
Plantago lanceolata L.	P	-	-	3.7	0.33	0.5	7.0	0.67	1.33	3.83
Achillea millefolium L.	P	6.67	7.67	34.67	3.33	17.83	47.67	0.5	23.2	79.8
Rumex acetosella L.), PP	P	-	0.33	-	-	0.83	-	0.25	0.3	-
Capsella bursa-pastoris L.	A	22.2	13.5	2.2	-	1.2	0.8	0.3	-	-
Plantago maior L.	P	9.0	6.3	1.0	8.0	8.8	0.5	3.7	4.5	0.2
Anagallis arvensis L., MP, PP	A	-	-	-	1.5	0.75	3.8	2.3	0.2	3.6
Chenopodium album L.	A	-	-	-	1.3	5.0	-	1.2	1.9	1.8
Lamnium purpureum L.	A	1.2	0.3	-	-	-	-	-	-	-
Potentilla reptans L., MP	P	-	-	4.5	-	0.5	0.6	-	-	-
Viola tricolor L. MP	A	-	-	0.2	-	-	-	-	-	-
Prunella vulgaris L., MP	P	-	-	-	-	-	0.2	-	-	-
Rumex acetosa L., MP	P	-	-	-	-	0.2	-	-	-	-
Artemisia vulgaris L., MP, PP	P	0.3	3.3	-	-	-	-	-	-	-
Polygonum aviculare L., MP	A	-	0.2	0.2	0.3	-	-	0.2	-	-
Geranium pratense L.	A	-	-	-	0.2	-	-	-	-	0.5
Total dicotyledonous herbs	-	92.53	66.1	88.64	120.96	109.28	114.73	113.45	101.01	176.31

Table 6. *Cont.*

Weed Species	**A/P**	**Plants per 1 m^{-2}**								
		Regrowths of the Sward								
		1			**2**			**3**		
		P	**H**	**NR**	**P**	**H**	**NR**	**P**	**H**	**NR**
Dicotyledonous weeds										
Stellaria media (L.) Vill.	A	16.7	3.7	22.5	20.2	15.9	14.8	19.5	13.7	14.8
Geranium molle L.	A	6.7	0.8	3.7	-	-	0.5	-	-	0.17
Cirsium arvense L.	P	0.5	0.5	0.3	0.2	-	-	0.1	-	-
Ranunculus arvensis L., PP	A	-	0.3	-	-	-	0.2	-	-	-
Ranunculus acris L., MP	P	-	-	0.3	-	-	0.2	-	-	0.3
Ranunculus repens L., PP	P	-	-	-	-	-	-	-	-	1.2
Erigeron canadensis L.	A	-	-	0.3	1.0	0.3	-	0.8	0.5	-
Crepis tectorum L.	A	-	-	-	-	-	11.3	0.5	-	15.8
Veronica arvensis L.	A	1.3	0.3	3.3	1.3	0.5	-	0.5	0.25	0.3
Sonchus asper L. Hill.	A	-	-	1.5	-	-	0.3	-	-	-
Cerastium arvense L.	P	-	-	-	-	-	-	1.3	1.0	-
Daucus carota L.	A/P	-	-	-	0.3	-	-	-	-	0.6
Convolvulus arvensis L., PP	P	0.2	-	-	-	-	-	-	-	-
Linaria voulgaris L., MP, PP	P	-	-	-	-	-	0.5	-	-	-
Aegopodium podagraria L.	P	-	0.2	-	-	-	-	-	-	-
Thymus serpyllum L.	P	-	-	-	-	-	0.3	-	-	-
Polygonum convolvulus L., PP	A	-	-	-	-		0.5	-	-	-
Galium aparine L.	A	-	-	-	-	-	0.2	-	-	-
Total dicotyledonous weeds		25.40	5.5	31.90	23.0	16.7	28.8	22.7	15.45	33.17
Sum of dicotyledonous herbs and weeds		117.93	71.6	120.54	143.9	125.98	143.53	136.15	116.46	209.48
Monocotyledonous weeds										
Echinochloa crus-galli L.	A	-	-	-	1.3	-	-	-	-	-
Poa annua L.	A	-	2.0	-	-	0.7	-	1.0	-	1.75
Setaria viridis L. P. Beauv.	A	-	-	-	-	-	-	0.25	0.5	-
Sum of monocotyledonous weeds	-	-	2.0	0.0	1.3	0.7	0.0	1.25	0.5	1.75
Horsetail										
Equisetum arvense L. MP, PP	P	0.3	-	-	-	-	-	-	-	-
Sum of dicotyledonous and monocotyledonous herbs and weeds and horsetail	-	118.23	75.6	120.54	145.2	126.68	143.53	137.40	116.96	211.23

A, annual; P, perennial; A/P, biennial; P, ploughing; H, harrow; NR, no renovation (control treatment); MP, medicinal plant; PP, poisonous plant (absolute weeds).

Under the conditions of this study, the herb group also comprised medicinal plants such as *Taraxacum officinale*, *Anagallis arvensis*, *Potentilla reptans*, *Viola tricolor*, *Prunella vulgaris*, *Rumex acetosa*, *Equisetum arvense*, *Artemisia vulgaris*, and *Polygonum aviculare*. In the weed group, medicinal properties characterized the species *Ranunculus acris* and *Linaria vulgaris*. Along with herbs and species of fodder value, some toxic plants were also found in the sward, such as *Rumex acetosella*, *Ranunculus arvensis*, *Ranunculus repens*, and *Linaria vulgaris*. In the sward under investigation, 10 toxic plant species were found. Five belonged to the herb group (*Taraxacum officinale*; *Rumex acetosella*; *Anagallis arvensis*; *Equisetum arvense*; *Artemisia vulgaris*), while another five to the weed group (*Ranunculus arvensis*; *Ranunculus repens*; *Daucus carota*; *Linaria vulgaris*; *Polygonum convolvulus*). In this study, the most numerous toxic species was *Taraxacum officinale*, which was present in the sward throughout the growing season. In the second and third regrowths, an increase in the number of *T. officinale* plants was observed. The remaining toxic plants occurred in the sward sporadically, and their rate of incidence per square meter was low (Table 6).

The average number of herbs and dicot weeds averaged over the years 2014–2016 was lowest in the first regrowth and generally increased in the second and third regrowths. In the first and second regrowths, the counts of dicot and monocot weeds and herbs were similar in the treatments after ploughing (P) and non-renovation (NR). In contrast, the non-renovated treatment (NR) showed the highest degree of weed infestation (NR; 211.23). Averaged across the years and regrowths of the experiment, the weed infestation rate was lowest in the sward obtained after breaking up the topsoil layer to a depth of 5 cm with a disk harrow (H). This shows that disking the topsoil prior to grassland reseeding (H) is more efficient in controlling weed growth compared to ploughing to a depth of 30 cm followed by full seedbed preparation (P). A probable reason behind the greater number of weeds in the plough treatment (P) is the light-induced germination of seeds in the soil seed bank brought up to the soil surface by ploughing (Table 6).

Generally, in the three-year period, there were 19 perennial species in the sward, 19 annuals, and one biennial species (*Daucus carota*) (Table 6). Annuals are easily subjected to elimination during mowing and grazing. In the first spring regrowth, the most numerous species to occur in the degraded sward was *Taraxacum officinale*. The species accounted for 32.5–45.64% of all herb and weed plants in the NR and H treatments, respectively. In the first regrowth, in the treatment renewed after ploughing (P), there was a fairly high incidence of *Capsella bursa-pastoris* (22.2 and 13.5 plants per square meter, respectively). These annual, segetal, and ruderal weeds rarely occurred in the treatments that involved compact disk harrowing for sward renewal (H), and their counts in the degraded sward (NR; 2.2 plants per square meter) (Table 6) were also low. In the first regrowth of the degraded sward (NR) the most numerous taxons were *Taraxacum officinale*, *Achillea millefolium*, and *Stelaeia media*. The remaining species, mainly annuals, occurred in small numbers and did not compromise sward yields. The counts of *Potentilla repens*, *Viola tricolour*, *Polygonum aviculare*, *Ranunculus acris*, *Erigegeron canadensis*, and *Sonchus asper* were also low in this sward regrowth.

Regardless of how the meadow under investigation was renovated, *Taraxacum officinale*, *Achillea millefolium*, *Plantago maior*, *Anagallis arvensis*, *Chenopodium album*, *Stellaria media*, *Erigeron canadensis*, *Crepis tectorum*, and *Veronica arvensis* were the most numerous species found in the second and third regrowths. The greatest populations of *Taraxacum officinale* and *Stelaria media* were found on the meadow plots renewed by ploughing and full tillage, while the smallest occurred in the sward established in the seedbed that had been prepared by compact disk harrowing (H). A large group of herbs and weeds occurred in the first and second regrowths, and they included *Glechoma hederacea*, *Lamnium purpureum*, *Potentilla reptans*, *Viola tricolor*, *Prunella vulgaris*, *Rumex acetosa*, *Artemisia vulgaris*, *Ranunculus arvensis*, *Linaria vulgaris*, *Aegopodium podagraria*, *Thymus serpyllum*, *Polygonum convolvulus*, *Galium aparine*, and *Echinochloa crus-galli*.

The values of Shannon–Wiener's diversity function (H') and Simpson's dominance index (*SI*) were affected by successive regrowths and, with the exception of the first regrowth, by whether or not seed renewal was performed (Figure 4). Thus, in the first regrowth, the values of both biodiversity indicators were similar for the two sward renewal methods and only slightly different from those for the non-renovated sward. Both the *SI* and H' values showed a slight tendency for decreased diversity in the renewed sward (treatments P and H) vs. the non-renewed control (NR). The calculated H' values for the sward renovated after ploughing (P; 1.648) and after the use of a compact harrow (H; 1.700) were similar. Likewise, Simpson's function value (*SI*) for the first showed the highest species biodiversity for the degraded sward (NR) and the lowest for soil disked to a depth of 5 cm with a compact harrow (H; Figure 4a). The lowest biodiversity following the use of a compact disk harrow (H) was the result of the sward having been dominated by four weed species: *Taraxacum officinale*, *Achillea millefolium*, *Capsella bursa-pastoris*, and *Stelaria media*. The differentiating effect of sward renovation vis-à-vis non-renovated sward became more apparent with successive regrowths and was particularly conspicuous for diversity as measured by the *H′* index values in the third regrowth. This was particularly true of sward reseeds on the plough-prepared seedbed (P), where the biodiversity underwent the greatest reduction with successive regrowths.

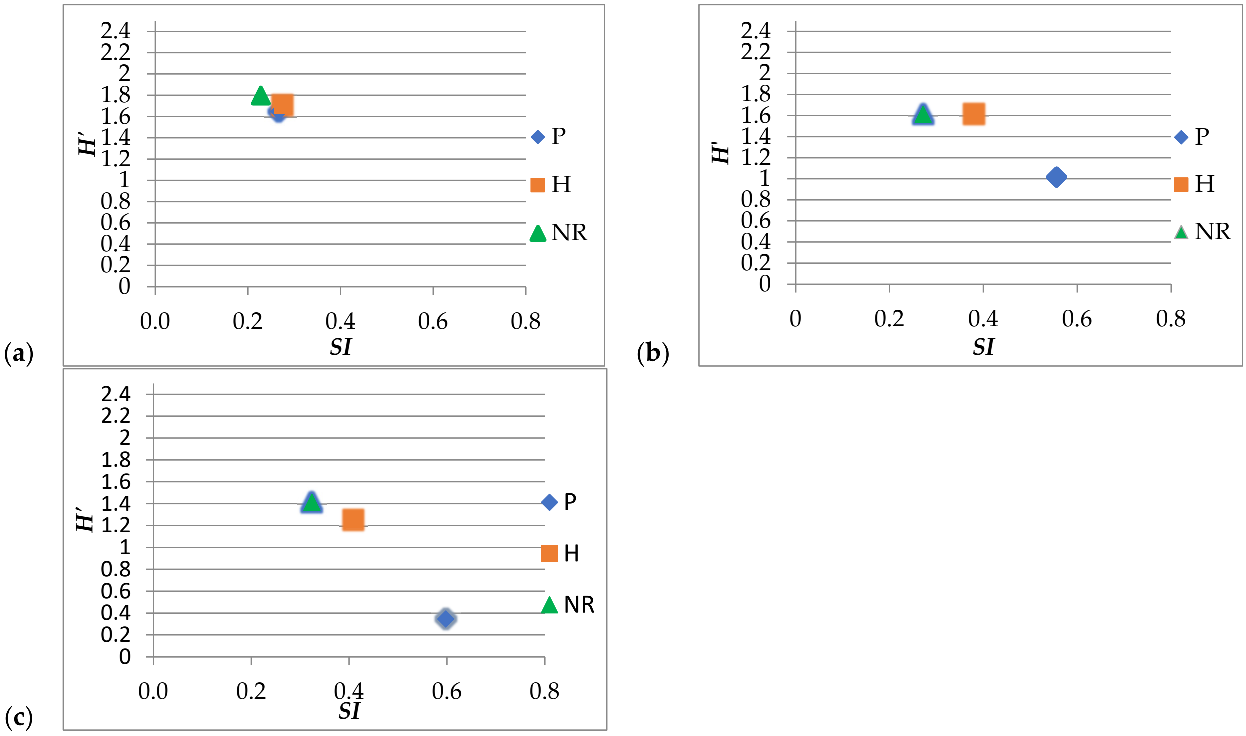

Figure 4. Three-year (2014–2016) averages of the Shannon–Wiener diversity index (*H′*) and Simpson's dominance index (*SI*) in the weed community of the grassland under investigation. Data arranged by regrowth: (**a**) First regrowth, (**b**) second regrowth, and (**c**) third regrowth; and by renovation method: P—ploughing, H—harrowing, and NR—non-renovation (control treatment).

In the second regrowth, the sward disked by a harrow prior to renovation (H) and the non-renovated sward (NR) showed the highest biodiversity, as expressed by the *H′* and *SI* indicators (Figure 4b). The third regrowth of the NR treatment showed the highest *H′* and the lowest *SI* values, meaning that the degraded sward (NR) had the highest biodiversity. Biodiversity was lowest in the seedbed prepared by full tillage after ploughing (P).

4. Discussion

This study, conducted under organic conditions, showed that grassland renovation by ploughing (P) and after the application of compact harrowing (H) significantly reduced the development of weeds compared to the degraded, non-renovated sward (NR). This was evidenced by the lower mean 2014–2016 weed weight and the higher biomass index in the renovated sward (P and H). The higher biomass index value obtained in our study on the renovated treatments indicates the competitiveness of the renovated sward toward the invading weeds. This confirms the negative correlation of crop biomass with weed biomass described earlier by Döring et al. [11].

Blumenthal et al. [28] emphasized that it is mainly annual weeds from the soil seed bank that colonize swards in the renovation year. In subsequent years, perennial weeds accounted for most of the weed weight, which was a consequence of, for example, grazing.

In this study, the yields of dry matter depended on the renovation method and varied with the consecutive regrowths of the sward. The highest yield of the renewed sward was recorded in the first regrowth, and then it declined.

The first regrowths of the sward reseeds in the P and H renovation treatments showed statistically significant increases in yield values averaged across the three years (2014–2016) over the yield recorded in the non-renewed treatment (NR). Thus, a beneficial impact of renovation on sward performance was confirmed; an effect also described by Martin et al. [14]. There are varied opinions concerning sward renovation methods and how they affect sward performance in consecutive sward harvests. Kayser et al. [35] believed that, besides the renovation method, sward yield is also affected by habitat conditions. A rapid decline in yields immediately after renovation was previously described by other authors [36]. In the literature, there are also several reports that failed to resolve the issue of which renovation method is more beneficial for sward yield, because similar results were obtained regardless of the renovation method adopted (ploughing, compact harrowing, or sward suppression by herbicide followed by direct seeding) [37].

Renovation involving ploughing (P) or harrowing (H) was demonstrated to keep weeds down more effectively compared to the treatment where no sward renovation was applied (NR). These results confirm the opinion expressed by other authors on the efficacy of deep ploughing for weed control in a degraded sward. Similarly to our findings, some researchers recorded fast rebounding of some difficult-to-control perennial weeds [15].

It was previously demonstrated that renewal by ploughing is beneficial for improvement of fodder yield and quality [38] but is harmful to the environment [39], since it leads to nitrogen losses, accelerates carbon metabolism in the soil, increases leaching of nitrates from the soil, etc. Invasive [10] and dicot weeds, some of which may be harmful to animals [9,15], are a particular hazard to grasslands. In this study, the value of the biomass index was lowest in the third regrowth: 75.54% for the plough treatment, 82.31% for the disk harrow treatment (H), and 63.27% for the degraded, non-renewed treatment (NR).

In this study, carried out under Poland's conditions, only 39 herb and weed species were identified, of which 92% were dicot plants. A much higher biodiversity was observed in New Zealand, where pastoral agriculture is developed. As many as 245 weed species from 42 families could be counted on New Zealand's pasturelands, the most numerous being *Jacobaea vulgaris* Gaertn., *Cirsium arvense* (L.), and *Achillea millefolium* (L.) [25,39].

Herbs in swards such as dandelion, chicory, ribwort plantain, and yarrow are appreciated, as they enrich the animal diet with vitamins, micro-elements, and other substances that foster good health and improve the metabolism and productivity of animals [15,17,20]. These aforementioned benefits of herbs make them components of choice in the seed blends used for grassland renovation, because such a sward is willingly ingested by animals [17,19]. The opposite is true for invasive weeds, which pose a substantial hazard to grassland biodiversity, as they make use of allelopathic interactions to displace valuable species, thereby causing economic losses and biological damage to swards [10].

In the renewed sward in this study, the presence of several toxic plant species was recorded, of which *Tataxacum officinale* was the most populous and present in the sward throughout the growing season. However, the species occurred in small numbers and posed no threat to animal life or health. Toxic plant species contain toxic chemical compounds dangerous to animals, causing them to succumb to various serious illnesses or even to die [9]. The toxic action of some plants appears after the digestion of green fodder, while in others, the toxic properties persist in hay or silage. Among the toxic plants, some, e.g., marsh horsetail, lose their toxic properties after ensiling. The occurrence of toxic plants in swards has also been reported by other researchers [15,20].

The sward renewed by ploughing (P) showed the highest biodiversity. A probable reason behind the greater number of weeds in the plough-based seedbed preparation in treatment P is the light-induced germination of seeds in the soil seed bank that were turned up to the soil surface by the plough. Blumenthal et al. [28] found the presence of 11,000–18,000 seeds per square meter of the soil of renovated meadows, where the majority were seeds of short-lived weeds. Janicka [15] also reported on an intensive growth of weeds from the soil seed bank after grassland renovation. In this study, the sward renewed by ploughing (P) showed the highest number of weeds under the conditions of arable field cropped to winter wheat. Feledyn-Szewczyk et al. [26] found ca. three times fewer weed seeds after ploughing than after simplified tillage and direct drilling. In contrast to these results, in this study, the lowest number of weeds was obtained after disking with a compact harrow (H), even though the disk harrow failed to destroy all of the roots of perennial weeds, as reported by Janicka [15]. On the contrary, Schuster et al. [29] demonstrated that the number of weeds infesting permanent grasslands declined over the years, and the critical biomass weight, beyond which the development of weeds over successive years was suppressed, was 4.7 tonnes of dry matter per hectare.

Achillea millefolium, *Capsella bursa-pastoris*, *Plantago maior*, *Stellaria media*, and *Geranium molle* were the most numerous of the herb and weed species occurring in the degraded (NR) and renewed (P and H) swards. Those species are widespread on grasslands, not only in Poland.

The high rate of occurrence of some species in the sward is not recommendable, due to the content of specific compounds, such as ranunculin in crowfoot or tannin in sorrel, which cause animals to avoid these plants and leave them ungrazed in the pasture [20]. As was emphasized previously, the compact disk harrowing used for superficial destruction of the degraded straw failed to eliminate all weeds. Specifically, weeds with large and stout roots, such as *T. officinale*, are fairly quick to rebound [15].

Capsella bursa-pastoris was fairly numerous in the sward renovated by the plough method (P). Conversely, the population of this species was reduced following renovation that involved compact harrowing (H). In another study that assessed the segetal diversity in the crops of pea and lupine, depending on the tillage system deployed, no presence of *C. bursa-pastoris* was found [27]. On the contrary, in winter wheat seeded after ploughing or after reduced tillage, a five-fold reduction in the number of this species was recorded vis-à-vis the crop established by direct drilling [26].

The degraded sward (NR) was characterized by the highest biodiversity, as expressed by Shannon-Wienner's index (H'). Similar results for the highest species richness and biodiversity in unchanged, i.e., non-renovated, treatments were obtained by Martin and Wilsey [8] and Wilsey et al. [40–44]. Plant biodiversity in swards is also impacted by animal grazing. A seven-fold increase in access to light by seedlings was recorded in a previous study after the sward had been renovated by undersowing, thereby making it possible for germinating seeds to develop into plants [8]. A greater number of species and more biodiversity can be achieved by rotational, rather than by continuous, grazing [41].

In this study, biodiversity was lowest in the seedbed prepared by full tillage after ploughing (P). Opposite results have been reported for pea and lupine, where greater biodiversity was found in ploughed vs. non-ploughed reduced tillage treatment [27]. In the grassland literature, greater biodiversity has been reported from grasslands that have resown spontaneously than from those that have been reseeded [42]. In another study, Tracy et al. [21] failed to demonstrate a relationship between weed plant number and species richness, and they proved that species composition and uniform distribution of different taxons in swards impact the values of the H' and SI indicators.

In the last few years, advanced technologies such as satellite imagery and remote sensing are used to determine diversity (H') and dominance (SI) indices, to manage field crops, and to monitor and control grazing animals [1,39,43–45]. Recognition of species by these advanced methods is impeded by the lack of experience in performing these assignments [44]. It is suggested that trainees should attempt to take many scans of different resolutions to acquire relevant skills, since an inadequate resolution may be either too poor to detect differences or, conversely, too high and, thus, carry superfluous information regarding the scanned surfaces [44].

5. Conclusions

As shown by a three-year study across the years 2014–2016, sward renovation on a tract of grassland performed using seedbed preparation, either by ploughing (P) or by topsoil disking with a compact harrow (H), resulted in an increase in dry herbage yield and biomass index, with a concomitant decrease in the average weed biomass as compared to the non-renovated sward (NR).

The highest dry herbage yields averaged over the three-year period (2014–2016) were obtained in the first regrowth, followed by a decrease in herbage yields in the subsequent years.

Grassland renovation carried out after ploughing (treatment P) and, to a much lesser extent, disking with a compact harrow (treatment H) restricted biodiversity, as measured by Shannon–Wiener's diversity function (*H′*), in comparison to the biodiversity in the non-renewed treatment (NR). Simpson's dominance index (*SI*) showed low values on the non-renewed control (treatment NR), with only three weed species dominating the sward: *Taraxacum officinale* Web., *Achillea millefolium* L., and *Stellaria media* L. Vill. These three species accounted for 78.7%, 80.8%, and 85.8% of the total number of weeds in the first, second, and third regrowths, respectively. After being renovated by the plough method (treatment P), the sward was dominated by *Taraxacum officinale* Web., *Achillea millefolium* L., *Capsella bursa-pastoris* L., *Plantago maior* L., *Chenopodium album* L., *Stellaria media* L., and *Veronica arvensis* L. Meanwhile, *Taraxacum officinale* Web., *Achillea millefolium* L., *Capsella bursa-pastoris* L., *Plantago maior* L., and *Stellaria media* L. prevailed in the sward established on soil disked to a 5 cm depth before reseeding (treatment H).

The results for the 2014–2016 average weed weight, sward yield, biomass index, Shannon–Wiener's diversity index (H′), and Simpson's dominance index (SI) showed a slowly progressing weed infestation of the sward after previous renovation. The appearance and increasing incidence of a small group of weeds, which may come to dominate the sward over the years, is alarming, as this may lead, after some time, to the need for repeated sward renovation.

Author Contributions: Conceptualization, E.G.; methodology E.G., M.G. and M.J.-S.; validation, E.G.; investigation, E.G., M.G., B.W. and M.J.-S.; data curation, M.G.; writing—original draft preparation, E.G.; writing—review and editing, E.G., B.W. and M.J.-S.; visualization, E.G., M.G., B.W. and M.J.-S.; supervision E.G., M.G., B.W. and M.J.-S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Miroslawa Węglarz, the owner of Agriland company, for donating, free of charge, the seeds of MFL legume–grass mixture for the renovation of the sward of a degraded grassland under ecological conditions.

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

References

1. Fauvel, M.; Lopes, M.; Dubo, T.; Rivers-Moore, J.; Frison, P.-L.; Gross, N.; Ouin, A. Prediction of plant diversity in grasslands using Sentinel-1 and -2 satellite image time series. *Remote Sens. Environ.* **2020**, *237*, 111536. [CrossRef]
2. Török, P.; Vida, E.; Deák, B.; Lengyel, S.Z.; Tóthmérész, B. Grassland restoration on former croplands in Europe: An assessment of applicability of techniques and costs. *Biodivers. Conserv.* **2011**, *20*, 2311–2332. [CrossRef]
3. Dusseux, P.; Hubert-Moy, L.; Corpetti, T.; Vertès, F. Evaluation of SPOT imagery for the estimation of grassland. *Int. J. Appl. Earth Obs. Geoinf.* **2015**, *38*, 72–77. [CrossRef]
4. Golka, W.; Żurek, G.; Kamiński, J.R. Permanent grassland restoration techniques—An overview. *Agric. Eng.* **2016**, *20*, 51–58. [CrossRef]

5. Burczyk, P.; Gamrat, R.; Gałczyńska, M.; Saran, E. The role grasslands in providing ecological sustainability of the natural environment. *Water Environ. Rural Areas* **2018**, *18*, 21–37.
6. Tiainen, J.; Hyvönen, T.; Hagner, M.; Huusela-Veistola, E.; Louhi, P.; Miettinen, A.; Nieminen, T.M.; Palojärvi, A.; Seimola, T.; Taimisto, P.; et al. Biodiversity in intensive and extensive grasslands in Finland: The impacts of spatial and temporal changes of agricultural land use. *Agric. Food Sci.* **2020**, *29*, 68–97. [CrossRef]
7. Milberg, P.; Tälle, M.; Fogelfors, H.; Westerberg, L. The biodiversity cost of reducing management intensity in species-rich grasslands: Mowing annually vs. every third year. *Basic Appl. Ecol.* **2017**, *22*, 61–74. [CrossRef]
8. Martin, L.M.; Wilsey, B.J. Assessing grassland restoration success: Relative role of seed additions and native ungulate activities. *J. Appl. Ecol.* **2006**, *43*, 1098–1109. [CrossRef]
9. DiTomaso, J.M. Invasive weeds in rangelands: Species, impacts, and management. *Weed Sci.* **2000**, *48*, 255–265. [CrossRef]
10. Goslee, S.C.; Peters, D.P.C.; Beck, K.G. Modeling invasive weeds in grasslands: The role of allelopathy in *Acroptilon repens* invasion. *Ecol. Model.* **2001**, *139*, 31–45. [CrossRef]
11. Döring, T.F.; Storkey, J.; Baddeley, J.A.; Collins, R.P.; Crowley, O.; Howlett, A.A.; Jones, H.E.; McCalman, H.; Measures, M.; Pearce, H.; et al. Weeds in organic Fertility-building leys: Aspects of species richness and weed management. *Org. Farming* **2017**, *3*, 51–65. [CrossRef]
12. Panetta, F.D.; James, R.F. Weed control thresholds: A useful concept in natural ecosystems? *Plant Prot. Q.* **1999**, *14*, 68–76.
13. Dąbrowska, T. Charakterystyka wybranych gatunków ziół i chwastów użytków zielonych. In *Trwałe Użytki Zielone w Gospodarstwie Ekologicznym*, 2nd ed.; Tyburski, J., Grzegorczyk, S., Eds.; Uniwersytet Warmińsko-Mazurski w Olsztynie: Olsztyn, Poland, 2013; pp. 85–114. ISBN 9788362863570.
14. Martin, L.M.; Moloney, K.A.; Wilsey, B.J. An assessment of grassland restoration success using species diversity components. *J. Appl. Ecol.* **2005**, *42*, 327–336. [CrossRef]
15. Janicka, M. Re-growth of original sward following meadow renovation by over drilling—central Poland. In Proceedings of the 3th Symposium on Integrating Efficient Grassland Farming and Biodiversity, Tartu, Estonia, 2–31 August 2005; Lillak, R., Viiralt, R., Linke, A., Geherman, V., Eds.; Estonian Grassland Society (EGS): Tartu, Estonia, 2005; Volume 10, pp. 625–628, ISBN 9985-9611-3-7.
16. Rayburn, A.P.; Laca, E. Strip-seeding for grassland restoration: Past successes and future potential. *Restor. Ecol.* **2013**, *31*, 147–153. [CrossRef]
17. Neciu, F.C.; Sãplacan, G.; Rechiţean, D.; Dragomir, N. Forage chicory (*Cichorium intybus* L.)—Pretability in crops and effects in ruminants feeding. *Anim. Sci. Biotechnol.* **2004**, *50*, 170–175.
18. Zając, M.; Spychalski, W.; Goliński, P. Effect of different methods of sward renovation on selected physical and chemical soil properties. In Proceedings of the 23rd EGF General Meeting on Grassland in a Changing World, Kiel, Germany, 29 August–2 September 2010; Schnyder, H., Isselstein, J., Taube, F., Auerswald, K., Schellberg, J., Wachendorf, M., Herrmann, A., Gierus, M., Wrage, N., Hopkins, A., Eds.; Estonian Grassland Society (EGS): Tartu, Estonia, 2010; Volume 15, pp. 226–228, ISBN 978-3-86944-021-7.
19. Seefeldt, S.S.; Stephens, J.M.C.; Verkaaik, M.L.; Rahman, A. Quantifying the impact of a weed in a perennial ryegrass-white clover pasture. *Weed Sci.* **2005**, *53*, 113–120. [CrossRef]
20. Harrington, K.C.; Thatcher, A.; Kemp, P.D. Mineral composition and nutritive value of some common pasture weeds. *N. Z. Plant Prot.* **2006**, *59*, 261–265. [CrossRef]
21. Tracy, B.F.; Renne, I.J.; Gerrish, J.; Sanderson, M.A. Effect of plant diversity on invasion of weed species in experimental pasture communities. *Bassic Appl. Ecol.* **2004**, *5*, 543–550. [CrossRef]
22. Wrage, N.; Strodthoff, J.; Cucillo, H.M.; Isselstein, J.; Kayser, M. Phytodiversity of temperate permanent grasslands: Ecosystem services for agriculture and livestock diversity conservation. *Biodivers. Conserv.* **2011**, *20*, 3317–3339. [CrossRef]
23. Bailey, K.; Derby, J.-A.; Bourdôt, G.; Skipp, B.; Cripps, M.; Hurrell, G.; Saville, D.; Noble, A. *Plectosphaerella cucumerina* as a bioherbicide for *Cirsium arvense*: Proof of concept. *BioControl* **2017**, *62*, 693–704. [CrossRef]
24. Auld, B.A.; Hetherington, S.D.; Smith, H. Advances in bioherbicide formulation. *Weed Biol. Manag.* **2003**, *3*, 61–67. [CrossRef]
25. Ghanizadeh, H.; Harrington, K.C. Weed management in New Zealand Pastures. *Agronomy* **2019**, *9*, 448. [CrossRef]
26. Feledyn-Szewczyk, B.; Smagacz, J.; Kwiatkowski, C.A.; Harasim, E.; Woźniak, A. Weed flora and soil seed bank composition as affected by tillage system in three-year crop rotation. *Agriculture* **2020**, *10*, 186. [CrossRef]
27. Bojarszczuk, J.; Podleśny, J. Segetal diversity in selected legume crops depending on soil tillage. *Agriculture* **2020**, *10*, 635. [CrossRef]
28. Blumenthal, D.M.; Jordan, N.R.; Svenson, E.L. Effects of prairie restoration on weed invasions. *Agric. Ecosyst. Environ.* **2005**, *107*, 221–230. [CrossRef]
29. Schuster, M.Z.; Gastal, F.; Doisy, D.; Charrier, X.; de Moraes, A.; Médiène, S.; Barbu, C.M. Weed regulation by crop and grassland competition: Critical biomass level and persistence rate. *Eur. J. Agron.* **2020**, *113*, 125963. [CrossRef]
30. Available online: https://agriland.pl/produkty/lucerna-w-mieszance/ (accessed on 30 September 2021).
31. Mirek, Z.; Piękoś-Mirkowa, H.; Zając, A.; Zajac, M. Flowering Plants and Pteridophytes of Poland a Checklist. In *Krytyczna Lista Roślin Naczyniowych Polski*; W. Szafer Institute of Botany, Polish Academy of Science: Kraków, Poland, 2002; p. 442.
32. Patriquin, D.G.; Bains, D.; Lewis, J.; Macdougall, A. Weed control in organic farming systems. In *Weed Control in Agroecosystems: Ecological Approaches*; Altieri, M.A., Liebman, M., Eds.; CRS Press: Boca Raton, FL, USA, 1988; pp. 303–317.

33. Shannon, C.E. A mathematical theory of communications. *Bell Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
34. Simpson, E.H. Measurement of diversity. *Nature* **1949**, *168*, 668. [CrossRef]
35. Kayser, M.; Müller, J.; Isselstein, J. Grassland renovation has important consequences for C and N cycling and losses. *Food Energy Secur.* **2018**, *7*, e00146. [CrossRef]
36. Elsaesser, M. Grassland renovation as a possibility for increasing nitrogen efficiency. *Grassl. Sci. Eur.* **2012**, *17*, 607–609. Available online: https://www.europeangrassland.org/en/infos/printed-matter/proceedings.html (accessed on 15 March 2022).
37. Gaweł, E.; Grzelak, M. Influence of grassland renovation methods on dry matter and protein yields and nutritive value. *Apple. Ecol. Environ. Res.* **2020**, *18*, 1661–1677. [CrossRef]
38. Terlikowski, J.; Barszczewski, J. The effectiveness of permanent grassland renovation under different soil and climatic conditions. *J. Res. Appl. Agric. Eng.* **2015**, *60*, 112–119. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-63f0c379-4afc-4425-b462-4edbff033181 (accessed on 15 March 2022).
39. Isselstein, J.; Kayser, M. Grassland renovation and consequences for nutrient management. In Proceedings of the 23rd International Grassland Congress 2015—Keynote Lectures, New Delhi, India, 20–24 November 2015; Grassland Production and Utilization. Roy, M.M., Malaviya, D.R., Yadav, V.K., Singh, T., Sah, R.P., Vijay, D., Radhakrishna, A., Eds.; Range Management Society of India: Jhansi, India, 2015; pp. 105–116.
40. Wilsey, B.J.; Chalcraft, D.R.; Bowles, C.M.; Willig, M.R. Relationships among indices suggest that richness is an incomplete surrogate for grassland biodiversity. *Ecology* **2005**, *86*, 1178–1184. [CrossRef]
41. Segar, R.; Li, G.Y.; Singh, J.S.; Wan, S.H. Carbon fluxes and species diversity in grazed and fenced typical steppe grassland of Inner Mongolia, China. *J. Plant Ecol.* **2019**, *12*, 10–22. [CrossRef]
42. Valkó, O.; Deák, B.; Török, P.; Kelemen, A.; Miglécz, T.; Tóth, K.; Tóthméerész, B. Abandonment of croplands: Problem or chance for grassland restoration? Case studies from hungary. *Ecosys. Health Sustain.* **2016**, *2*, e01208. [CrossRef]
43. Mazur, P.; Chojnacki, J. Remote grasslands crop productivity measurements with usage of multispectral camera and small unmanned aerial vehicle. *J. Res. Appl. Agric. Eng.* **2018**, *63*, 151–154.
44. Wang, R.; Gamon, J.A.; Cavender-Bares, J.; Townsend, P.A.; Zygielbaum, A.I. The spatial sensitivity of the spectral diversity-biodiversity relationship: An experimental test in a prairie grassland. *Ecol. Appl.* **2018**, *28*, 541–556. [CrossRef]
45. Gholizadeh, H.; Gamon, J.A.; Townsend, P.A.; Zygielbaum, A.I.; Helzer, C.J.; Hmimina, G.Y.; Yu, R.; Moore, R.M.; Schweiger, A.K.; Cavender-Bares, J. Detecting prairie biodiversity with airborne remote sensing. *Remote Sens. Environ.* **2019**, *221*, 38–49. [CrossRef]