



## Article

# The Influences of Different Methods of Grassland Renovation on the Weight of Post-Harvest Residues and the Abundance of Selected Soil Nutrients

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Received: 4 September 2020; Accepted: 14 October 2020; Published: 16 October 2020



**Abstract:** In Poland, half of the grassland is neglected and requires renovation, which was the reason for starting this research project. The aim of this research was to study the grassland habitat of lowland central Poland that has water-deficient, slightly acidic mineral soil, in the years 2013–2016. Specifically, the impact of three methods of grassland renovation on the dry matter yield and the weight of post-harvest residues, as well as on the content of particular nutrient components in the soil, were determined. Three legume–grass mixtures were used for the renovation. The study shows that the method of renovation (ploughing, harrowing, and herbicide + direct sowing) did not have a significant effect on the dry matter yield nor on the weight of the post-harvest residues or the content in the soil of some nutrients. The highest yield was obtained from the “Original” mixture with 50% of legumes in the seed mix. After the renovation, 5.03–7.17 t·ha<sup>−1</sup> of post-harvest residues were obtained (mainly grasses and roots of plants, 68.7–71.1%). After three years from renovation, the soil pH significantly decreased and the content of Ca and Mg increased, while the nitrogen, phosphorus, potassium, and C<sub>org</sub> compounds remained at an unchanged level. The concentration of various forms of nitrogen, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, Ca, and C<sub>org</sub> decreased in the deeper soil layer (down to 60 cm).

**Keywords:** grassland renovation; forage production; legume–grass mixtures; post-harvest residue; stubble; roots; N-NH<sub>4</sub>; N-NO<sub>3</sub>; C<sub>org</sub>

## 1. Introduction

On a global scale, grasslands cover 3 billion hectares and account for 23% of the land area [1]. Grasslands produce feed for animals that, in turn, generate meat, milk, and dairy products for about one billion people [2]. The global grassland area is constantly changing, and over the years, its percentage in the agricultural area in individual countries of the temperate zone has ranged from 75% in Ireland to about 20% in Poland [3]. According to Lesschen et al. [4], in Europe, grassland occupies about one third of the agricultural area and plays an important role in the production of animal feed and food for humans, as well as exerts a positive impact on the natural environment. The environmental role of grassland is, inter alia, to maintain plant and animal biodiversity, prevent loss of nutrients, mainly carbon and nitrogen, increase soil biological activity, mitigate the effects of climate change, provide biomass for energy purposes, prevent various types of erosion, and provide positive landscape-related aesthetic experiences to the population [1,2,4–6]. In Poland, according to the latest Statistics Poland data [7], permanent grassland covers an area of 2.754 million hectares and is unevenly distributed across the whole Poland. The largest areas of permanent grassland in Poland are located in the following

voivodeships: Mazowieckie, Podlaskie, Małopolskie, Warmińsko-Mazurskie, and Wielkopolskie. The average feed yield obtained from 1 ha of grassland in Poland is low and amounts to about 4.63 tons of dry matter [7]. In some European countries (Germany, France, the Netherlands), the productivity of grassland is twice that of Poland [4].

In the recent 30 years, Europe has seen a decrease in the area of grassland, which, in addition to producing roughage for animals, performs various environmental functions: hydrological, landscape, biocenotic, climatic, anti-erosion, and even aesthetic. Currently, more attention is paid to the non-productive, environmental impact of grassland than to its economic function in animal husbandry and food production [1,4,8–10]. The milder climate in Western Europe makes permanent and short-term grassland the main sources of fodder for grass-grazing animals (often also during the winter season). It is the cheapest way to use the sward and make animal products [1,3]. In Poland, however, hay and meadow use is more widely known and practiced than grazing use. The political and economic transformations in Poland in the 1990s led to a decline in the number of grassland animals and to the establishment of larger livestock farms. Therefore, interest in the cultivation and use of grassland sward has dropped [1,3,11]. Currently, many grasslands in Poland are neglected and do not guarantee high yields and good quality feed. According to Golka et al. [12], up to 50% of Polish meadows and pastures have been degraded, destroyed, neglected, and are in bad need for renovation in order to restore them to the system of production of low-cost, valuable roughage. There are many causes of grassland sward degradation, the most important being inappropriate use of the sward, excessive weed infestation, inadequate fertilization, delaying the date of the first cut, lack of legumes in the sward, periodic or prolonged droughts, excessive moisture in the soil, and prolonged unilateral use of the sward, e.g., for grazing animals [12].

Grassland renovation is carried out in order to increase the level of yields, enrich the sward with valuable species of grasses, and introduce small-seeded legumes appreciated for their nutritional value for animals and positive impact on the environment. However, after the renovation of the sward, positive results are not always achieved. Velthof et al. [6] in the third year after renovation by ploughing method did not find any improvement in yields. They observed higher nitrogen losses from soil in the renovation treatment vs. the control, i.e., unrenovated, degraded grassland plots. Different results were obtained by Golka et al. [12]. In their study, an increase in yields by 0.6–1.2 t·ha<sup>−1</sup> after the application of a wide-strip overseeding aggregate occurred already in the first cut harvested in the year following the undersowing.

Renovation of grassland is carried out by fertilisation and rational use: undersowing of the low-cut sward in the traditional way or with special machines, after previous chemical or mechanical destruction of the old sward with a harrow or a rotary tiller, or by direct sowing [5,6,8,9,13–23]. The ploughing of a degraded sward and a full set of cultivation treatments before sowing of the seed mixture are considered to be the most radical, costly, and environmentally unfavourable method of grassland renovation as it destroys the soil structure. In addition, by aeration of the soil, nitrogen and phosphorus are released from the organic matter of the soil. These components are then washed away into deeper soil layers in soluble forms [2,6,18,19,23]. Under the conditions of renovation carried out after the previous destruction of the sward with herbicide, the leaching of soluble carbon compounds was found to be 10–30% higher than after ploughing under the conditions of grassland fertilization with and without manure [18,19]. According to Eekeren et al. [9], ploughing renovation destroys and limits the population of soil microorganisms, which may take up to 10 years to recover. Due to the significant decrease in the organic matter content of the soil, other methods of renovation are considered to be better than those involving ploughing and full tillage [5]. In the study of Gawel and Grzelak [15], a comparison of three grassland renovation methods gave similar production results, and under conditions of moisture deficits in the soil, better sward conditions for growth were created for legumes than for grasses. Direct or strip sowing in a low-cut sward of degraded grassland or, after suppressing the development of the old sward with herbicide and sowing the new seed mixture with specially designed seed drills, allows, according to Golka et al. [12] and

Mocanu and Hermenean [21], the reduction of the costs related to energy consumption and the cost of seeds. It also reduces yield losses and enriches the sward with valuable legume and grass species. According to Kayser et al. [17], all grassland renovation methods increase sward productivity, provided that valuable species of small-seeded legumes and grasses are present in the sward and that the sward is used properly.

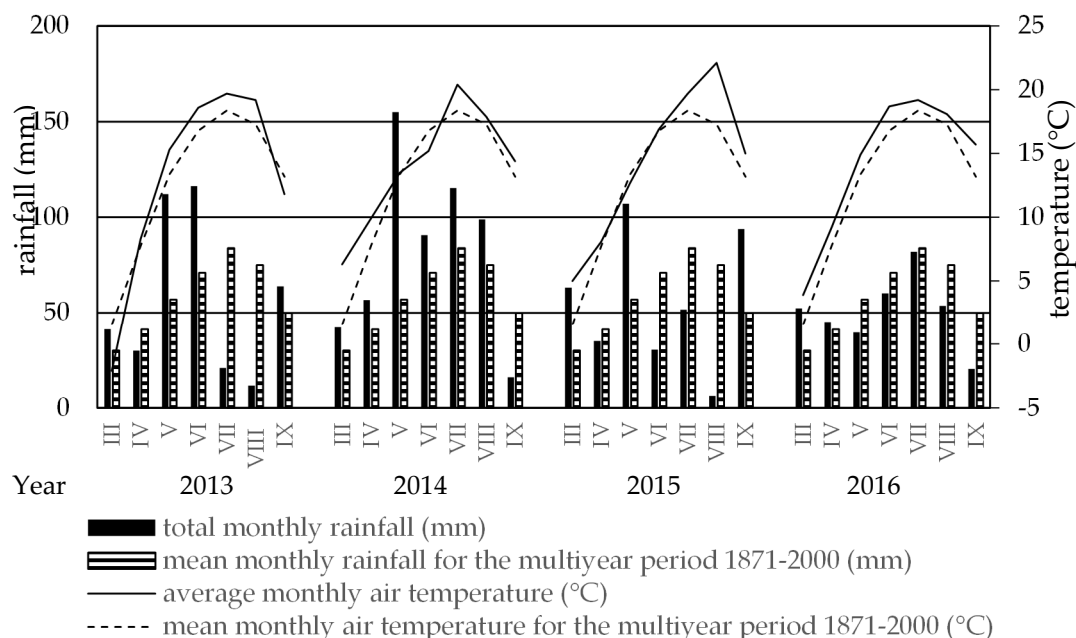
After reviewing the available literature on grassland renovation, it was decided to use the experiment site a to conduct a follow-up study aimed at assessing the impact of three grassland renovation methods on yields and nutritional value of feed, the results of which are described in the article by Gawęł and Grzelak [15]. The additional study was concerned with the influence of the renovation methods on the weight of post-harvest residues and the content of basic nutrients in the soil.

The specific aim of this investigation was to study the influence of the selected methods of grassland renovation on the weight of post-harvest residues after three years of using mixtures, and to determine the content (mineral and total) of nitrogen compounds as well as the available forms of phosphorus, potassium, magnesium, total calcium, and organic carbon in the soil.

## 2. Materials and Methods

A two-factor field experiment was carried out at the Agricultural Experimental Unit of the Institute of Soil Science and Plant Cultivation—State Research Institute in Grabów, Mazowieckie Voivodeship (51°21' N; 21°40' E), Poland, in the years 2013–2016. The first factor of the experiment included three methods of grassland renovation: 1—ploughing and sowing the seeds of legume–grass mixtures; 2—compact disc harrowing (topsoil loosening to the depth of 5 cm) and sowing seeds of the mixtures with a seed drill; and 3—herbicide and direct sowing. The second factor included three brands of legume–grass seed blends K—Krasula: *Lolium perenne* L. (25.7%); *Lolium multiflorum* Lam. (9.2%); *Phleum pratense* L. (13.8%); *Dactilis glomerata* L. (9.2%); *Festuca rubra* L. (9.1%); *Festuca arundinacea* Schreb. (9.1%); *Festuca ovina* L. (4.6%); *Trifolium pratense* L. (4.5%); *Medicago sativa* L. (4.5%); *Agrostis alba* L. (1.8%) + 3.5 kg *Trifolium repens* L. “Romana” (8.1%); total legumes = 17%, 50% of the standard for sowing legumes plants in relation to their pure sowing, with a seed sowing rate—40 kg·ha<sup>−1</sup>; C—Cent 4: *Lolium perenne* L. (40.0%); *Lolium multiflorum* Lam. (10.0%); *Festuca arundinacea* Schreb. (15.0%); *Festuca pratensis* Huds. (5.0%); *Phleum pratense* L. (5.0%); *Poa pratensis* L. (5.0%); *Festulolium braunii* (K. Richt.) A. Camus (5.0%); *Medicago sativa* L. (10.0%); *Trifolium repens* L. (5.0%); total legumes = 15%, 50% of the standard for sowing legumes plants in relation to their pure sowing, seed sowing rate—35 kg·ha<sup>−1</sup>; O—Original: *Trifolium repens* L. “Barda” (10.0%); *Medicago x varia* Martyn Fl. Rust. “Radius” (20.0%); *Trifolium pratense* L. “Milena” (20.0%); *Lolium perenne* L. “Artemis” (15.0%); *Dactilis glomerata* L. “Amila” (15.0%); *Festuca pratensis* Huds. “Anturka” (10.0%); *Festulolium braunii* (K. Richt.) A. Camus “Agula” (10.0%) in pure sowing; total legumes = 50%, 50% of the standard for sowing legumes plants in relation to their pure sowing, seed sowing rate—23 kg·ha<sup>−1</sup>. The experiment was established on Umbrisols and Phaeozems, according to FAO-WRB soil classification system of 2014. Renovation of degraded grassland was carried out in mid-June 2013 under good humidity and thermal conditions, to avoid the ill effects of heavy and unevenly distributed precipitation that occurred in May of that year (Figure 1). Seed germination and initial plant growth took place under suitable and favourable humidity and thermal conditions. In the year of sowing, weather conditions worsened in the summer, as there was less precipitation compared to the long-term average for that period. In the first year after the renovation (2014), the average monthly rainfall from March to August exceeded the long-term average. As a result, the growth and development of the mixtures proceeded well, and four sward harvests were gathered in the growing season. The highest storm rainfall in the first year after renovation (2014) was recorded in May. In the second production year (2015), the precipitation in May, June, and September exceeded the long-term average. Temperatures higher than the long-term average and the lack of precipitation in the remaining period inhibited the plant regrowth and development of the mixture swards. In that year, only three sward harvests were made during the growing season. The third production year (2016) was warm and dry. March happened to be the only month with precipitation

higher than the long-term average, and the soil moisture deficiency in the remaining months was significant. As in the previous year, only three sward cuts were collected. During the experiment, the weather conditions in the winter season did not limit the persistence of the plants in mixtures, as there were no sudden and long-lasting drops in air temperature. The largest, short-term falls in air temperature were recorded in January 2014 and 2016. They were  $-2.6^{\circ}\text{C}$  and  $-3.6^{\circ}\text{C}$ , respectively.



**Figure 1.** Meteorological conditions in the years 2013–2016 at Grabów (Poland) during the growing season.

A two-factor field experiment was established using the split-block method with four replications. The area of the entire experiment was 0.6 ha, while the area of one plot was 100 m<sup>2</sup>. In the year of sowing, the mixture sward was grazed with cows. In the subsequent years, alternate use of the sward was practised. In total, during the three years of utilization, six sward cuts for hay-silage and nine grazing sessions were performed in a short-session system (2–3 days of grazing) with a cattle rate of 79–85 cows. In the sowing year, in order to prevent weeds from developing, the entire area of the experiment was mowed twice for haylage. In the fall of the same year, cows were grazed. In the first year of use (2014), two haylage swaths were mowed and two grazing sessions were conducted. In the second and third years of use, the spring regrowth of sward was mowed and the next two were grazed with cattle. In both years, the yield in the autumn regrowth of the sward was low. Therefore, it was put to grazing by cattle without prior evaluation of the yield level and botanical analysis of the species composition of the sward. The stocking density of the pasture ranged from 2.8 to 3.0 livestock units per 1 ha (LSU·ha<sup>-1</sup>). The stocking density, expressed in body weight of grazing cows, ranged from 39.5 to 42.5 t·ha<sup>-1</sup>.

Pre-sowing fertilization was 60 kg P<sub>2</sub>O<sub>5</sub>·ha<sup>-1</sup> and 60 kg K<sub>2</sub>O·ha<sup>-1</sup>. Each spring of each growing season, the following rates were applied: 80 kg P<sub>2</sub>O<sub>5</sub>·ha<sup>-1</sup>, 36 kg K<sub>2</sub>O·ha<sup>-1</sup>, and 34 kg N·ha<sup>-1</sup>. After cutting the first sward regrowth, 60 kg K<sub>2</sub>O·ha<sup>-1</sup> in the first year of use, 40 kg K<sub>2</sub>O·ha<sup>-1</sup> in second and third year, and 31 kg N·ha<sup>-1</sup> was applied. In each production year, 31 kg N·ha<sup>-1</sup> was applied after cutting the second and third sward regrowth.

The green matter yield was determined on the basis of green matter taken from 10 m<sup>2</sup> of each plot. The analysis of sward species composition was carried out for each regrowth, in 0.5 kg green fodder samples taken during the harvest (cut/grazing). The combined percentage proportions were calculated for lucerne, clover, and white and meadow clover, as well as for grasses (all species together) and weeds in the total dry matter of the ample.

In the autumn of the third year of use after the harvest of 2016 had been completed, samples of the post-harvest residues were taken and determined for weight and the share of the aboveground biomass (stubble) and belowground biomass (roots) fractions in each of the four replicates of each treatment. For this purpose, all plants were dug out from an area of 1 m<sup>2</sup> and separated into legumes, grasses, and weeds. Stubble post-harvest residues were cut to a height of 5 cm above the ground (above-ground residues), i.e., grasses from the tillering node and legumes from the root crown to the height of the old stubble, while roots were removed from the top soil layer to 15 cm (root fraction). The green and dry weight of the aboveground fraction (stubble biomass) and roots (belowground biomass) were determined for each group of plants (legumes, grasses, and weeds). Prior to the setup of the 2013 experiment and in the autumn of 2016, after the last cut was made in the third year of use, soil samples were taken from a depth of 30 and 60 cm. A randomized block design considering the renovation methods was used to collect the soil samples. The samples were taken from each plot and combined into appropriate grassland renovation treatments. The samples were analysed for the contents of water and dry matter as determined by the weighting method (according to the standard PB 5.1-edition II-10. 09. 2004), N-NH<sub>4</sub> and N-NO<sub>3</sub> mg·kg<sup>-1</sup> by flow analysis (CFA) (according to the standard PB 8.1 edition IV-02. 05. 2012), N total = (N-NH<sub>4</sub> + N-NO<sub>3</sub>), content of N<sub>min</sub>·kg·ha<sup>-1</sup> = (4.5 × N total), pH<sub>KCl</sub> by the potentiometric method (according to PN ISO 10390: 1997), available phosphorus content P<sub>2</sub>O<sub>5</sub> by the spectrophotometric method (according to PN-R-04024:1996), available potassium content K<sub>2</sub>O by emission atomic spectrometry (according to PN-R-04022: 1996+Az1:2002), available magnesium content Mg by Flame Atomic Absorption spectrometry (FAAS) (according to PN-R-04020:1994+Az1:2004), calcium content by Inductively Coupled Plasma spectroscopy (ICP) (according to PB 111.1-wyd.I-10.04.2013), and total organic carbon (TOC) by titration (red oximetry) (according to PB 20.1-edition I-20.05.1999).

Statistical analysis of the weight of the post-harvest residues was carried out in a system of four replications and two-factorial experiments, in which the research factors were the same: three methods of grassland renovation (Factor I; 1—ploughing, 2—harrowing, and 3—herbicide + direct sowing) and three mixtures used in the sward renovation (Factor II; K—Krasula, C—Cent 4, and O—Original). Calculations were performed in the program Statistica (Stat Soft Inc., Tulsa, OK, USA).

The data on soil chemical composition came from a bifactorial design where Factor 1 comprised three sward renovation methods, and Factor 2 was the years of the experiment (2013 and 2016). Two-way ANOVA without replications where the interaction of Factors 1 × 2 was the experiment error was used to process the input data. Tukey's test ( $p \leq 0.05$ ) compared the mean values for the factors tested in the experiment.

### 3. Results

#### 3.1. Sward Yields

The methods of grassland renovation under comparison did not have a significant effect on the total dry matter yield of the mixtures from three years of use (Table 1). No renovation × mixture interaction was found throughout the experiment. The low coefficient of variation ( $v\% = 10.04$ ) indicated a small variability in the total yield of the three years of sward use after renovation (Table 1). A tendency was observed for the improvement of the yield of swards in the treatment renovated by ploughing and full tillage (Treatment 1) by 8.8% compared to the yield obtained after herbicide application and direct sowing of legume–grass mixtures with the “Moore type” direct drill (treatment 3). The dry matter yield was also lower by 4.2% in the treatment with a harrow vs. that obtained after renovation performed with the ploughing method (Treatment 1).

**Table 1.** Influence of the usage of the renovation of the grassland and species composition of legume–grass mixtures on the total dry matter yield of 3 years ( $\text{t}\cdot\text{ha}^{-1}$ ).

Mixtures (B)	Grassland Methods Renovation (A)			
	1	2	3	Means
Krasula	31.24	26.92	26.98	28.38AB
Cent 4	27.65	26.65	23.95	26.09A
Original	28.89	30.61	29.70	29.74B
Means	29.26a	28.06a	26.88a	
LSD <sub>0.05</sub> for A—n.s.; B = 2.468; B/A—n.s.; A/B—n.s.; RSD = 6.62; v% = 10.4				

1—ploughing; 2—harrowing; 3—herbicide + direct sowing; RSD—Residual Standard Deviation; v%—coefficient of variation. K—Krasula: *Lolium perenne* L. (25.7%); *Lolium multiflorum* Lam. (9.2%); *Phleum pratense* L. (13.8%); *Dactylis glomerata* L. (9.2%); *Festuca rubra* L. (9.1%); *Festuca arundinacea* Schreb. (9.1%); *Festuca ovina* L. (4.6%); *Trifolium pratense* L. (4.5%); *Medicago sativa* L. (4.5%); *Agrostis alba* L. (1.8%) + 3.5 kg *Trifolium repens* L. “Romana” (8.1%); C—Cent 4: *Lolium perenne* L. (40.0%); *Lolium multiflorum* Lam. (10.0%); *Festuca arundinacea* Schreb. (15.0%); *Festuca pratensis* Huds. (5.0%); *Phleum pratense* L. (5.0%); *Poa pratensis* L. (5.0%); *Festulolium braunii* (K. Richt.) A. Camus (5.0%); *Medicago sativa* L. (10.0%); *Trifolium repens* L. (5.0%); O—Original: *Trifolium repens* L. “Barda” (10.0%); *Medicago x varia* Martyn Fl. Rust. “Radius” (20.0%); *Trifolium pratense* L. “Milena” (20.0%); *Lolium perenne* L. “Artemis” (15.0%); *Dactylis glomerata* L. “Amila” (15.0%); *Festuca pratensis* Huds. “Anturka” (10.0%); *Festulolium braunii* (K. Richt.) A Camus “Agula” (10.0%) in pure sowing; A; B—values in column marked with the same letter are not significantly different; a—values in line marked with the same letter are not significantly different.

Significantly higher dry matter yield was obtained from the “Original” mixture. ( $29.74 \text{ t}\cdot\text{ha}^{-1}$ ) vis-à-vis the Cent 4 mixture (Table 1). In the “Original” mixture, the percentage of legume seeds accounted for 50% of their sowing norm in pure sowing. The lowest yielding mixture was Cent 4 (Table 1).

The proportion of the components in the sward was altered by each of the three renovation methods (ploughing, harrowing, and herbicide and direct sowing). A detailed description of these changes in all the sward regrowth over the three years of use is presented in the study by Gawel and Grzelak [15]. It shows the dominance of grasses, which accounted for 72 to 93% of the renovated sward in the first regrowth. According to that study, initially white and meadow clover were the most numerous legume species in the sward. With time, an increasing deficit in rainfall caused clovers and grasses to disappear from the sward. In the third year of use, lucerne, as a species more resistant to drought than clovers, dominated in the sward. In the study by Gawel and Grzelak [15], large changes in the sward were noted compared to the proportions of components in the seed blends. The average percentages of grasses, legumes, and weeds changed over the years of use (Table 2). In the first year after the renovation (2014), grasses prevailed, especially in the treatments renovated by ploughing and harrowing. During this period, a similar percentage of legumes in the renovated sward was obtained using the methods under comparison (after ploughing, after harrowing, and after the herbicide application). In the first year after renovation, the highest average annual weed infestation (about 17%) was recorded under herbicide application, which restricted the development of the old sward. In the following years of use (2015 and 2016), the average percentage of grasses in the mixtures decreased to about 46.2–49.9% in the third year. During that time, the average share of legumes increased. In the third year after the renovation (2016), the biggest increase in weed infestation compared to that in the first year was in the sward renovated with the ploughing method (an increase by 11.8%). After the renovation with a harrow, weed infestation in the third year increased by 8.6%, while after herbicide by only 4.2% compared to that in the first year after the renovation.



**Table 2.** Share of components in the dry matter yield of legume–grass mixtures depending on the method of sward renovation and of the species composition mixture in 2014–2016 (%).

Factor	Share of Components in Mixtures (%)								
	Years								
	2014			2015			2016		
	L	G	W	L	G	W	L	G	W
Methods of grassland renovation (A)									
1	65.32	26.79	7.88	49.72	44.53	5.75	46.25	34.05	19.70
2	65.35	24.59	10.06	52.16	41.31	6.53	49.97	31.39	18.64
3	57.72	25.00	17.27	56.39	36.46	7.15	50.75	27.71	21.54
Mixtures (B)									
K	66.57	22.92	10.50	56.80	36.77	6.43	48.85	30.68	20.46
C	62.98	20.63	16.39	55.43	35.45	9.12	45.22	27.84	26.95
O	58.85	32.83	8.32	46.04	50.09	3.87	52.89	34.64	12.46

1—ploughing; 2—harrowing; 3—herbicide + direct sowing; K—Krasula; C—Cent 4; O—Original; L—Legumes; G—Grasses; W—Weeds.

In the first and second year after the renovation, all mixtures were dominated by grasses in the sward. The average annual percentage of legumes in the mixtures differed from the expected one and was 22.9% for the plots seeded with Krasula (Treatment K) and 20.6% for those seeded with Cent 4 (Treatment C), respectively. The largest amount of legumes (32.8%) was obtained in the plots seeded with the Original mixture (Treatment O), which gave the equivalent of 50% of the legume seeding rate used in pure sowing (Table 2). The weed infestation of the mixture sward also varied among the treatments. In the sowing year, the average annual weed infestation of the treatments seeded to Krasula (Treatment K) and to the Original (Treatment O) was low but increased in the third year after renovation, especially in the case of Cent 4 (Treatment C), where the weed infestation reached 26.9%. During the three years of use, Original was the least weed-infested treatment. In terms of balancing the percentage of grasses and legumes in the sward during the three-year period, Treatment O was the most effective.

### 3.2. Post-Harvest Residues

The dry weight of post-harvest residues was similar regardless of the sward renovation method applied and the species composition of the mixtures used in the study (Table 3). No effect of interaction of the studied factors on the weight of the post-harvest residue was found. The high value of the coefficient of variation indicates a strong variability for the yield of dry matter of the aboveground (stubble) and belowground parts (roots) and for the total yield of post-harvest residues left by legumes and weeds. The yield of post-harvest residues from grasses showed an average to strong variability, while the total weight of post-harvest residues of legumes, grasses, and weeds exhibited small variability.

**Table 3.** Comparison of the dry matter of post-harvest residues by fraction (legumes plants, grasses, and weeds) as well as by stubble and roots in t·ha<sup>−1</sup>.

Factor	Legume			Grass			Weeds			Total		
	S	R	Σ	S	R	Σ	S	R	Σ	S	R	Σ
Methods of renovation												
1	0.62	1.26	1.88	0.98	2.41	3.35	0.22	0.39	0.61	1.77	4.06	5.84
2	0.61	1.01	1.62	1.04	2.53	3.57	0.11	0.34	0.44	1.76	3.87	5.63
3	0.31	0.48	0.79	1.26	3.25	4.51	0.12	0.43	0.55	1.69	4.16	5.85
LSD <sub>0.05</sub>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Mixtures												
K	0.45	0.54	0.99	1.07	2.48	3.56	0.11	0.37	0.47	1.64	3.39	5.03
C	0.50	0.74	1.24	0.73	2.35	3.09	0.27	0.53	0.79	1.50	3.62	5.13
O	0.59	1.47	2.05	1.43	3.35	4.78	0.07	0.27	0.34	2.08	5.08	7.17
LSD <sub>0.05</sub>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Coefficient of variation (v%)												
v%	69.7	99.0	89.4	39.6	41.9	38.3	99.0	89.5	61.3	27.4	32.7	29.2

1—ploughing; 2—harrow; 3—herbicide + direct sowing; S—stubble (aboveground biomass); R—roots (belowground biomass); K—Krasula; C—Cent 4; O—Original; n.s.—non-significant differences.

In the third year after the renovation, in autumn, a total of 5.63–5.85 t·ha<sup>−1</sup> of dry matter of the post-harvest residues was left behind in the soil. Among the components of the mixtures, most post-harvest residues were left by grasses (3.35–4.51 t·ha<sup>−1</sup>), particularly as a grass root fraction (Table 3). In total, 59.5% of the total weight of the harvest residues in the treatment with ploughing (Treatment 1), 63.8% in the treatment with a harrow (Treatment 2), and 74.7% in the treatment with a herbicide and pure sowing (Treatment 3) were left by grasses.

The species composition of the mixtures used in grassland renovation did not have a significant effect on the total weight and weight of the individual fractions of the post-harvest residues. After harvesting the herbage, a total of 5.03 to 7.17 t·ha<sup>−1</sup> of the aboveground and root part of the residues remained in the soil. Most of these residues were left by the Original mixture (Treatment O) (7.17 t·ha<sup>−1</sup>) (Table 3). Legumes in this mixture left almost twice as much post-harvest residues compared to the other mixtures (Krasula, Cent 4). Particularly, a high weight of root residues was collected from the Original mixture (Treatment O) (1.47 t·ha<sup>−1</sup>; 27.1% of the total weight of the post-harvest residues for this mixture). The weight of the post-harvest residues left by weeds was not very large, and it was proportional to their percentage in the mixture sward. For particular renovation methods, it amounted to 13.6% after ploughing (Treatment 1), 8.6% after harrowing (Treatment 2), and 11.7% after herbicide and direct sowing (Treatment 3) (Table 3). The weeds infesting the swards of individual mixtures left a small weight of post-harvest residues, while their amount was the greatest (17.7%) on plots seeded with Cent 4 (Treatment C).

The weight of the post-harvest residues after the renovation of the sward was dominated by the roots of legumes, grasses, and weeds (Table 4). The highest percentage of roots in the post-harvest residues was found in the treatment with direct sowing performed after the killing of the old sward growth with a herbicide containing glyphosate as an active substance (71.1%). In turn, the smallest percentage was obtained from Krasula (treatment K; 67.4%). The percentage of root fraction in the weight of the post-harvest residues of the remaining mixtures was about 3% higher than that of Krasula.



**Table 4.** Yield ( $\text{t}\cdot\text{ha}^{-1}$ ) and percentage of roots in the dry matter of post-harvest residues remaining after applying the legume–grass mixtures.

Treatments	Total Post-Harvest Residue ( $\text{t}\cdot\text{ha}^{-1}$ )	Roots ( $\text{t}\cdot\text{ha}^{-1}$ )	Share of Roots in Post-Harvest Residue Weight (%)
Methods of renovation			
1	5.84	4.06	69.5
2	5.63	3.87	68.7
3	5.85	4.16	71.1
LSD <sub>0.05</sub>	n.s.	n.s.	-
Mixtures			
K	5.03	3.39	67.4
C	5.13	3.62	70.6
O	7.17	5.08	70.8
LSD <sub>0.05</sub>	n.s.	n.s.	-

1—ploughing; 2—harrow; 3—herbicide + direct sowing; K—Krasula; C—Cent 4; O—Original; n.s.—non-significant differences.

### 3.3. The Content of Minerals in the Soil

The method of grassland renovation had no significant effect on the content of various forms of nitrogen ( $\text{N-NH}_4$ ,  $\text{N-NO}_3$ , N total) nor did it affect the content of  $\text{N}_{\text{min}}$  expressed in  $\text{mg}\cdot\text{kg}^{-1}$  in the arable soil layer (30 cm) (Table 5). The contents of these forms of nitrogen in the soil before the renovation in 2013 and in autumn of the third year after the renovation were similar. The field tests were carried out under slightly acidic conditions, the  $\text{pH}_{\text{KCl}}$  of the soil ranging from 6.20 to 6.54. In the three years after the renovation, a significant decrease in soil acidity was noted, but it was still within the range of a slightly acidic reaction.

The contents of the available phosphorus and potassium forms in the soil before and after renovation were similar (Table 5). The concentration of available forms of magnesium and calcium in the treatment with renovation carried out after using a harrow (Treatment 2) was significantly higher than that found after ploughing and herbicide application, or direct sowing (Treatments 1 and 3) (Table 5). In the three years after the sward renovation, the content of available forms of Mg and Ca in the soil largely increased (Table 5). The method of grassland renovation had no significant impact on the soil abundance in  $\text{C}_{\text{org}}$  (%). In the treatment that involved chemical inhibition of sward development with herbicides and sowing with seeds with a direct seed drill (Treatment 3), a 0.19% to 0.47% lower organic carbon content was obtained than in the treatments renovated with the method of ploughing or loosening the top soil layer to a depth of 5 cm (Treatments 1 and 2, respectively). In three years after the renovation, a tendency of insignificant, slight accumulation of organic matter in the soil was observed.

The comparison of the content of various forms of nitrogen determined at two soil depths showed that the highest amount of  $\text{N-NH}_4$  occurred in the topsoil layer, especially in the treatment after ploughing (Treatment 1). The  $\text{N-NH}_4$  content decreased at a deeper soil depth (Table 6). On the other hand,  $\text{N-NO}_3$  was the highest in the soil after ploughing and after using a harrow (Treatments 1 and 2). After these two methods of grassland renovation, the soil structure was disturbed. During ploughing and soil displacement with the harrow, a large amount of post-harvest residues from the damaged sward entered the soil, which probably accelerated the process of organic matter mineralization in the soil. Probably that is why an increase in the content of various forms of nitrogen in the soil was observed. In this study, the  $\text{N}_{\text{min}}$  content was medium to high and very high. The acidity was similar at the compared soil depths (Table 6). In the deeper layers of the soil, the contents of P, K, Mg, Ca, and  $\text{C}_{\text{org}}$  decreased (Table 6).

**Table 5.** Comparison of the content of particular components in the soil before and after the renovation of grassland (in the 30 cm layer of soil).

Specification	Years Test Date	N mg·kg <sup>-1</sup> Soil			Calculated Content N <sub>min</sub> kg·ha <sup>-1</sup>	Soil pH <sub>KCl</sub>	Macroelements Absorbable Form mg (100 g) <sup>-1</sup> Soil			Total Calcium		Corg (TOC) %
		N-NH <sub>4</sub>	N-NO <sub>3</sub>	N Total			P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Mg	mg·kg <sup>-1</sup> Soil	%	
1	2013	8.42	17.15	25.57	115.06	6.54	15.11	6.32	14.15	2600	0.32	1.86
	2016	5.79	9.49	15.28	68.76	6.20	16.23	5.27	16.33	3683	0.36	2.30
2	2013	2.68	21.05	23.73	106.79	6.52	12.16	9.09	15.82	3500	0.42	2.44
	2016	5.22	16.44	21.66	97.47	6.30	10.87	5.49	17.89	4526	0.46	2.29
3	2013	6.90	12.51	19.41	87.35	6.50	11.92	6.34	14.54	2600	0.30	1.86
	2016	5.81	10.05	15.86	71.37	6.30	10.65	5.27	16.02	3725	0.38	1.93
Mean	-	5.80	14.45	20.25	91.13	6.39	12.82	6.29	15.79	3439	0.373	2.11
Analysis of variance												
Research factor 1: Methods of renovation												
1		7.11	13.32	20.43	91.91	6.37	15.67	5.79	15.24a	3131a	0.34a	2.08
2		3.95	18.75	22.69	102.13	6.41	11.51	7.29	16.86b	4013b	0.44b	2.36
3		6.35	11.28	17.64	79.36	6.40	11.28	5.80	15.28a	3162a	0.34a	1.89
NIR		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	1.568	206.98	0.096	n.s.
Research factor 2: Years; test date												
2013 year; before renovation		6.00	16.90	22.90	103.07	6.52b	13.06	7.25	14.83a	2900a	0.35	2.05
2016 year; after renovation		5.61	11.99	17.60	79.20	6.26a	12.58	5.34	16.74b	3978b	0.40	2.17
LSD <sub>0.05</sub>		n.s.	n.s.	n.s.	n.s.	0.188	n.s.	n.s.	0.935	123.4	n.s.	n.s.

1—ploughing; 2—harrow; 3—herbicide + direct sowing; n.s.—non-significant differences; a; b—values in column marked with the same letter are not significantly different.

**Table 6.** Comparison of the content of particular components at two soil depths (30 and 60 cm) before, and at 30 cm after grassland renovation.

Specification	Soil Sampling Depth (cm)	N mg·kg <sup>-1</sup> Soil			Calculated Content N <sub>min</sub> kg·ha <sup>-1</sup>	Soil pH <sub>KCl</sub>	Macroelements Absorbable Form mg·(100g) <sup>-1</sup>			Total Calcium		Corg (TOC) %
		N-NH <sub>4</sub>	N-NO <sub>3</sub>	N Total			P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Mg	mg·kg <sup>-1</sup> Soil	%	
2013 year												
1	30	8.42	17.15	25.57	115.06	6.54	15.11	6.32	14.15	2600	0.32	1.86
	60	1.06	8.24	9.30	41.85	6.53	6.04	4.75	11.93		0.27	0.80
2	30	2.68	21.05	23.73	106.79	6.52	12.16	9.09	15.82	3500	0.42	2.44
	60	1.36	9.76	11.12	50.04	6.81	4.86	4.49	10.11		0.33	0.91
3	30	6.90	12.51	19.41	87.35	6.50	11.92	6.34	14.54	2600	0.30	1.86
	60	0.85	3.65	4.5	20.25	6.55	3.00	6.16	9.87		0.24	0.47
2016 year												
1	30	5.79	9.49	15.28	68.76	6.20	16.23	5.27	16.33	3683	0.36	2.30
2	30	5.22	16.44	21.66	97.47	6.30	10.87	5.49	17.89	4526	0.46	2.29
3	30	5.81	10.05	15.86	71.37	6.30	10.65	5.27	16.02	3725	0.38	1.93

1—ploughing; 2—harrow; 3—herbicide + direct sowing.

## 4. Discussion

### 4.1. Weather Conditions

It is known from the literature that the thermal and humidity conditions of meadow soils affect the efficiency of mineralisation of nitrogen compounds in soil [13,24,25] and that the content of  $N_{\min}$  in autumn depends on the weather conditions occurring in the first half of the year (in the summer) [26]. Therefore, in our studies, an influence of different weather conditions, especially precipitation deficit in the years 2015 and 2016 on the content of  $N-NH_4$ ,  $N-NO_3$ ,  $N_{\min}$ ,  $P_2O_5$ ,  $K_2O$ ,  $Mg$ ,  $Ca$  total, and  $C_{org}$  in soil, was expected. In the humid year (2013), higher leaching and nutrient losses from the soil were recorded than in the year with precipitation deficiency and air temperatures higher than the long-term average (2016), which is consistent with literature reports [18,19]. Diacono and Montemurro [13] also observed large nitrogen losses caused by leaching in the autumn–winter period. In the literature, there are diverging opinions on how the weather conditions influence the content of the mineral components in the soil. For example, Sapek [25] showed a positive effect of temperature and no significant influence of soil moisture on the efficiency of the first nitrification stage (ammonification).

### 4.2. Dry Matter Yield

In the literature on grassland renovation, different opinions on the impact of renovation methods on sward yields are encountered, as already mentioned in the chapter “Introduction”. In some cases, grassland renovation improved the yields of the degraded sward. Hermenean et al. [27], using direct sowing, achieved quick upgrading of the degraded sward with a legume–grass mixture, with minimal damage to the old sward. In turn, Velthof et al. [6] did not record any increase in yields of intensively managed permanent grasslands that was renewed with a seed mix containing 100% perennial ryegrass in the subsequent three years after reseeding, but the herbage showed an improvement in feed quality. According to these authors, the beneficial effect of the renovation will be valid when the increase in yield after 3 years from the renovation is equal to the yield loss in the renovation year [6]. In another study, as a result of the renovation, yields dropped by 10%, but other benefits were obtained, such as an increase in the raw protein content of fodder after enrichment of the renovated sward with small-seeded legumes [8]. In other studies, no positive effects of grassland renovation were found. For example, Isselstein and Kayser [16] showed the negative effects of renovation that were manifested as a rapid decrease in yield and a long return of the sward to its pre-renovation condition.

Most of the literature on renovation is focused on the comparison of the yield and quality of renovated vs. degraded swards [6,8,27]. Few studies compare the yield of a sward resulting from different renovation methods [16,17,23]. Grassland ploughing is most often viewed as the most invasive renovation method leading to reduced yields and negative environmental impact [5]. It was also shown that the use of agricultural machinery to loosen the soil and move the top layer of the soil also has a negative impact on the soil environment [23]. Golka et al. [12], while analysing the impact of various methods of grassland sward renovation (including fertilization and rational use, application of herbicide with glyphosate as the active substance and ploughing of degraded sward, strip sowing, and selective use of herbicide), indicated that strip sowing with a specially constructed seed drill was the most efficient method of renovation. In the year following the strip-sowing, their research showed an increase in yield by  $0.8\text{--}1.2\text{ t}\cdot\text{ha}^{-1}$  of dry matter already in the first cut [12]. No significant differentiation of dry matter yields under the influence of grassland renovation methods (ploughing, harrowing, and herbicide and direct sowing) compared in the experiment was found in our study. Therefore, because of the similar yield level, these renovation methods can be considered suitable for use under the conditions of the Agricultural Experimental Unit Institute of Soil Science and Plant Cultivation—State Research Institute Grabów (Poland) [15].

Over the three years of utilization, the Original mixture (Treatment O) gave a significantly higher total dry matter yield than did Cent 4 (Treatment C) (Table 1). The species composition of the former seed blend consisted of the largest number of small-seeded legumes, which probably contributed to the

high yield. The legumes present in the Original seed blend could participate in symbiosis with bacteria fixing nitrogen from the air, thus providing additional nutrients to the remaining components of the mixtures, and thereby increasing the yield of the Original mixture. Similar observations concerning high yields of swards with a large proportion of legumes were presented by Diacono and Montemurro [13] and Eekeren et al. [9].

#### 4.3. Percentage of Components

Seasonal changes in the proportion of legumes in the sward and an increase in the proportion of legumes in summer, in the period of precipitation deficit, were also noted by Fuchs et al. [28]. They considered strip sowing made with specially constructed seeders to be very beneficial as its application was followed by rapid regeneration of the old sward, which resulted in small yield losses [12]. The application of a glyphosate-containing herbicide does not completely eliminate all weeds from the renovated sward [29]. This phenomenon was also observed by the authors of this study (Table 2). All these observations permit the assumption that the most severely weed-infested swards are obtained when the renovation scheme includes herbicide followed by direct mixture seeding (Treatment 3) (Table 2). In Treatment 3, problematic perennial weeds, such as *Taraxacum officinale* F.H. Wigg and *Achillea millefolium* L. quickly regenerated and grew back. Herbs have a beneficial effect on animals, improving their health and performance, especially when fed fresh [1]; but, their high proportion in the sward is not advisable. For nutritional considerations, the most suitable and sought herbage to be fed to herbivorous animals comes from a sward that contains a balanced proportion of grasses and legumes plants. The balance between monocot and dicot plants in the sward is also important because of the other ecosystem services provided by grassland to the environment [9]. In our research, after including weeds in the dicotyledonous plant pool, the most balanced composition of components was obtained in the years 2014–2015 from the plots seeded with the Original seed blend (Treatment O) (Table 2).

#### 4.4. Weight of Post-Harvest Residues

The available literature shows that the weight of the post-harvest residues left after harvesting the legume–grass mixtures can be significant and to vary depending on cultivation and harvest conditions. In our research, large root residues remained after the Original mixture. This was probably due to the large percentage of meadow clover and lucerne, i.e., plant species with a strongly developed root system in the seed mixture compared to pure sowing. This may have contributed to a large weight of roots left in the topsoil layer. For example, under organic conditions, it ranged, e.g., from 5.09 t·ha<sup>−1</sup> to 7.99 [30]. However, with different frequencies of mowing tufts of ungrazed herbage on the pasture, it ranged from 9.51 to 16.71 t·ha<sup>−1</sup> [31]. Together with the weight of post-harvest residues, significant amounts of nutrients are brought into the soil. For example, the legume–grass mixtures left behind the following: N—55.06–122.3 kg/ha; K—27.1–31.83 kg/ha; P—9.39–18.6 kg/ha; Ca—28.49–46.48 kg/ha; and Mg 11.57–18.74 kg/ha [31]. Observations carried out in our research have shown that a bigger post-harvest weight is left by grasses, mainly in the root fraction (Tables 3 and 4). On an organic pasture, the root fraction accounted for 67.5 to 83.5% of the total weight of the post-harvest residues [30]. In other studies, the significant predominance of roots in the yield of the post-harvest residues was also obtained, compared to the amount of the above-ground fraction [5,9,17,32]. According to Reinsch et al. [5], the root weight increases with the age of the plants, the biggest increases taking place in spring during intensive plant growth. At the beginning of the growing season, Thivierge et al. [32] achieved smaller root growths of the lucerne–grass mixture as compared to the grass sward, but in the later part of the season, the root elongation index of the mixture was much higher. Kayser et al. [17] believe that after renovation of grassland in a temperate climate by ploughing, the grassland sward needs 2–3 years to rebuild the root biomass to the state from before the renovation.

#### 4.5. Nutrients

Similar contents of different forms of nitrogen in the soil, under permanent grassland utilized for 3 years following the renovation with three methods, indicates slow mineralization in the soil (Table 5). It should be stressed that the deficiency in precipitation in the years 2015 and 2016 combined with the worsening thermal conditions, air temperature in the summer being higher than the long-term average, may have contributed to nitrogen losses from the soil. In this study, a medium to high and very high  $N_{\min}$  content in the soil was obtained (Table 6). It can therefore be assumed that part of the nitrogen will be unused by the new grassland sward. Furthermore, a comparison of the content of the nitrogen forms ( $N-NH_4$ ,  $N-NO_3$ ,  $N$  total, and  $N_{\min}$ ) before renovation and 3 years after renovation showed a downward trend in the content of those forms of nitrogen in the soil. Sapek [25] demonstrated a large influence of temperature and precipitation on the mineralisation efficiency of nitrogen compounds in meadow soils. Increased content of  $N_{\min}$  in the soil in the summer, and its decrease in the winter half-year, was also described by Pietrzak [24]. Other authors have had a similar opinion on this subject (Fuchs et al., 2018). Different results, however, were obtained by McDonald et al. [19] in the wet year, because in their research the use of herbicide to suppress old sward development before undersowing contributed to higher  $N_2O$  emissions than that after ploughing.

The effect of an increased concentration of nitrogen compounds available to plants in the soil after ploughing renovation method described in the literature [8,13,16,23] was not achieved in our study (Table 5). It is considered that the date of ploughing has a large impact on possible nitrogen losses, whereas ploughing in spring allows nitrogen losses to be significantly reduced compared to those resulting from renovation performed in autumn [6]. In other studies, Kayser et al. [17] found higher losses of  $N_2O$  from grassland renovated after ploughing than after herbicide inhibition of sward development.

Intensive grassland management promotes the accumulation of nitrogen and carbon compounds in the soil in comparison with extensively used land [33]. Klumpp et al. [34], apart from the intensity of use, emphasize the importance of the dose of fertilisers used and the manner of sward use (grazing vs. mowing) as they affect the content of nitrogen compounds in the soil by shaping the percentage of legumes and grasses in the sward of mixtures. Mixtures with a high percentage of legumes provide more nitrogen to the soil than grass mixtures, which, according to Elgersma and Sørensen [10], should be taken into account in studies on global climate warming. Degradation affects both the mineral nitrogen compounds and nitrogen bound by papillary bacteria living in symbiosis with legumes, and the transfer of biologically bound nitrogen to grasses is important for the nutrition of these plants and the entire environment [9,35]. Fuchs et al. [28] emphasise that the percentage of clover of up to 44% in the sward mixture does not increase  $N_2O$  emissions into the atmosphere.

As shown in Table 5, the total calcium content in the soil layer up to 30 cm was the highest in the treatment with herbicide and direct sowing (Treatment 3), and significantly increased in three years after the grassland renovation. Similarly, the content of magnesium, which together with calcium takes part in the symbiosis process, changed in the soil. The results are confirmed by data from the literature, e.g., from the study by Wielgusz et al. [36], who believes that legumes quickly deplete calcium from the soil as it is essential for the process of symbiosis with papillary bacteria. Of different opinion on the acidification of soil by legumes are Paul et al. [37], as they found an improvement in acidity in the top layer of soil on which underground clover was grown, leaving a large weight of Ca-rich plant residues. According to Wielgusz et al. [36], the soil under legumes also has good conditions for the development of proteolytic bacteria (decomposing protein) and the development of nitrifying bacteria, whereas ammonification bacteria are inhibited [36]. As a result of these processes, excess nitrogen compounds that cannot always be used entirely by plants are released to the soil.

In our study, the method of grassland renovation had no significant effect on the content of phosphorus and potassium in the soil (Table 5). However, literature data describe changes in the content of these components depending on the method and year since the renovation [23]. In that study, the content of phosphorus in the soil ( $P-PO_{4-3}$ ) generally increased in the third year after renovation,



and there was an increase or decrease in  $K^+$  content depending on the renovation methods used [23]. Medaj et al. [38], on the other hand, found a higher calcium content in the topsoil layer, which decreased in the deeper layers (14–21 cm).

The content of  $C_{org}$  indirectly affects soil productivity and calcium losses are a sign of soil degradation [5,16,18,23]. Regardless of the method of grassland renovation (after ploughing, after a harrow, and after herbicide; Treatments 1, 2 and 3), the  $C_{org}$  contents found in this study were similar (Table 5). It also did not change in three years after the renovation compared to the initial content before the renovation (Table 5). This shows the lack of progress in sward degradation. The main weight of carbon, according to a study by Klumpp et al. [39], is accumulated in the top-soil layer (20–60 cm), and a higher degree of carbon sequestration is observed in permanent pastures than in meadows. It is known from the literature that even single ploughing of grassland leads to the loss of carbon and to a release of  $CO_2$  into the atmosphere [5,13,16,18,19,24]. As a rule, grassland soils are richer in organic matter than arable soils and the organic matter content correlates with nitrogen content [24]. According to Zajac et al. [23], any loosening of the soil, ploughing, or the use of a rototiller or a harrow before reseeding of the sward with a seed mixture leads to losses in organic matter as a result of mineralisation and nitrogen losses.

## 5. Conclusions

Under the conditions of the AEU of the Institute of Soil Science and plant Cultivation—State Research Institute in Grabów (Mazowieckie Voivodeship, Poland), a similar total forage yield from three years of use and a similar weight of post-harvest residues were obtained for the compared sward renovation methods (ploughing—Treatment 1; harrowing—Treatment 2; and herbicide inhibition of sward development and direct sowing with a slotted sowing machine—Treatment 3).

The plots seeded with the Original seed mix (Treatment O) exhibited the highest yield and weight of post-harvest residues, a balanced proportion of legumes and grasses, and the lowest weed infestation of the sward.

In the third year after the renovation, between  $5.03 \text{ t} \cdot \text{ha}^{-1}$  and  $7.17 \text{ t} \cdot \text{ha}^{-1}$  of post-harvest residues remained on the grassland, in which 68.7–71.1% were plant roots, including grass roots amounting to  $2.35\text{--}3.35 \text{ t} \cdot \text{ha}^{-1}$ . The method of renovation and the species composition of the sward had no significant effect on the weight of the post-harvest residues left by the renovated sward.

After renovation, there was a slowdown of the mineralization process in the soil under the grassland. In the three years after the renovation, a slight acidification of the soil and a significant increase in calcium and magnesium content of the soil occurred, while the concentration of other nutrients and organic carbon remained unchanged.

Significant increases in the calcium and magnesium contents of the soil were found under the renovation treatment that involved harrowing and moving the topsoil to a depth of 5 cm, and the contents continued to rise for three years after renovation. The contents of  $N-NH_4$ ,  $N-NO_3$ , N total, calculated content of  $N_{min}$ ,  $P_2O_5$ ,  $K_2O$ , Mg, total calcium, and  $C_{org}$  decreased at a depth of 60 cm.

The calculated values in excess of  $100 \text{ kg } N_{min} \text{ kg} \cdot \text{ha}^{-1}$  allow the assumption that, at certain periods, part of the nitrogen will remain in the soil unused by the grassland sward.

**Author Contributions:** Conceptualized and did the experiment, wrote the manuscript, collected test results, analyzed the data, designed the experiment, carried out field tests, and reviewed the literature—E.G.; statistical analysis, reviewed the literature, revised the manuscript—M.G. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

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

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