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Effect of Different Renovation Methods on the Productivity of Mid-Forest Meadows as Foraging Areas for Free-Living Red Deer Population

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Abstract: Mid-forest meadows are integral to maintaining biodiversity and ecological services in forested landscapes but face degradation due to various reasons. This study evaluated the effectiveness of renovation methods on sward yield and herbage quality in two mid-forest meadows in northwestern Poland (54°10′ N, 16°78′ E), aiming to maintain their function as the foraging areas for the free-living red deer population. The results indicated that overdrilling was insufficient to significantly enhance sward quality or productivity (with no significant differences in DM yield between treatment and control), largely due to competition with existing vegetation and suboptimal habitat conditions. The full tillage method, in combination with sowing dedicated seed mixtures, substantially improved the sward yielding and forage quality, especially in terms of DM yield (av. 7% on object W; 18% on object TD). The efficacy of renovation methods varied between experimental sites, suggesting that the renovation strategy of mid-forest meadows should be tailored according to the habitat conditions.

Keywords: mid-forest meadows; seed mixture; quality of herbage; renovation; yield

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1. Introduction

The ongoing socio-ecological processes are heightening the importance of environmental services not only within individual ecosystems but also across their entire complexes. "Eco-efficiency", the intensification of production, with a simultaneous decrease in the impact on other habitats [1], is becoming increasingly important in environmental management. On the one hand, there is a growing focus on the quality of habitats, the ecological well-being of populations, and the conservation of wildlife. On the other hand, it is essential to maintain the land area used for forests and crops to meet society's needs [2,3].

The competing objectives outlined above are leading to more frequent clashes between foresters, farmers, and wildlife, particularly involving wild ungulates. In addition to providing compensation for crop damage, there is also a pressing need to take proactive measures to minimize such incidents. One potential approach is to establish dedicated areas with abundant forage to attract the animals' attention away from farmers' crops.

In the conditions of Central Europe, such lands can be mid-forest meadows. They play a specific role in the environment [4]. Due to their characteristics, they have an impact on biodiversity (at all levels and approaches), nutrient flow in ecosystems, and the ecology of plants and animals. In many cases, glades can be characterized as ecotones, with all the advantages of ecological niches [5]. Nevertheless, the open habitats within consistently managed forest complexes are not a significant element of the Central Europe landscape.

Historically, since the 19th century, the focus on the productive aspect of rural areas has led to the neglect of potential benefits associated with maintaining mid-forest meadows [5–7]. Currently, with sustainable approaches to the environment, where production is not the only factor for managed lands, the possible utilization of mid-forest meadows can be brought back to the attention. After all, the word "forest" in its original meaning did not refer to woods and production but to the places designated to preserve game species for hunting [8].

In most places with a temperate climate, maintaining open habitats is strictly correlated with their exploitation by humans and livestock or by wild ungulates [9–12]. Neglected grasslands undergo a gradual decline in their forage potential (amount of biomass, herbage quality of harvested yield, and plant diversity), which ultimately leads to degradation, succession towards shrubs and forested areas, or the transformation of these lands into other types of crops [13–17]. Since the 1930s, over 90% of semi-natural meadows in Europe have been transformed [18]. It is especially important in ecotone habitats, where succession tends to be accelerated.

While in the right conditions, the sward of mid-forest meadows can be attractive for animals on its own, in many places (especially among the managed forests), those areas, like all permanent grasslands in Poland, are the subject of degrading factors, e.g., site and climate changes promoting unfavorable (in foraging perspectives) species [19–21]. Decreasing yield and nutritional value can be reverted through proper management activities. Appropriate renovation activities, destructive or not for old swards [20,22], combined with an effective management strategy, are necessary to ensure the quality of produced biomass [23–25]. The intensity of such treatments should be adjusted to the level of competition between all present plant species and desired ones.

Renovation should be tailored to the preferred goal, e.g., requirements of the main herbivores species that will utilize this area. Deer are more selective in comparison to cattle as they also look for the highest amount of available biomass and its "greenness" [26,27]. Deer prefer green grasses in the spring and forbs in the summer and tend to avoid patches with dead plant materials [26]. However, offering the proper quality sward can influence their behavior throughout the seasons [28]. Of course, patchy grazing by animals causes the uneven utilization of swards [29], which impacts the efficiency of such areas [30]. It is purposeful to connect the extensive foraging activity of wild animals with other techniques (e.g., mowing) to prolong the stability of sward productivity [31].

Good-quality mid-forest meadows, as foraging places, can be a tool to control the populations of wild ungulates, with possible influences on the damage within forests and arable crops [32,33]. Besides providing feed, forest grasslands offer a sense of security due to their proximity to wooded areas, making them preferred even when nearby crops might provide slightly better forage.

The aim of the study was to evaluate the effectiveness of mid-forest meadow renovation using different methods in terms of both the quantity and quality of the sward yield. The renovated meadows were utilized as the foraging areas for the free-living deer population.

2. Materials and Methods

2.1. Experimental Site

The study was carried out from 2014 to 2017 on two selected mid-forest meadows in northwestern Poland (54°10′ N, 16°78′ E) by the Department of Grassland and Natural Landscape Sciences, Poznan University of Life Sciences, in cooperation with Polanów Forest District (Polish State Forest).

This study was conducted on the area managed by the Forest Wildlife Breeding Centre, characterized by a higher density of herbivore wildlife animal populations, in this case, red deer, compared to adjacent areas.

2.2. Weather Data

Meteorological data for Polanów (Table 1), collected from the Visual Crossing platform [34] and analyzed using the Vinczeffy Climatic Index (VCI) [35], indicated that the meteorological conditions in the experimental area generally reflected the conditions across northwestern Poland [36]. In 2013, the average VCI values classified the year as "medium-wet" (>0.151 mm/°C), with stable conditions observed during the vegetation season (April to October). In contrast, 2014 experienced extremely dry conditions (0.082 mm/°C) throughout most of the year, characterized by very low precipitation coupled with higher-than-average temperatures. Dry conditions persisted through the first half of the 2015 vegetation season (April to July). While meteorological conditions improved from August onward, the overall year was still classified as very dry (0.106 mm/°C). In comparison, 2016 and 2017 recorded notably higher VCI values (above 0.200 mm/°C), which placed them in the "rainy" category.

Table 1. Monthly average temperatures (Temp) [°C], total precipitation (Precip) [mm], and values of Vinczeffy Climatic Index (VCI) [mm/°C] for the experimental area in the subsequent years.

Month	2013			2014			2015			2016			2017		
	Temp	Precip	VCI	Temp	Precip	VCI	Temp	Precip	VCI	Temp	Precip	VCI	Temp	Precip	VCI
January	−1.9	40.3	-	−2.0	21.6	-	1.8	29.5	0.525	−2.2	27.0	-	−1.2	37.0	-
February	−0.4	32.8	-	3.2	3.0	0.034	0.9	6.1	0.234	2.7	43.7	0.565	0.1	42.5	-
March	−1.9	13.3	-	5.6	19.6	0.113	4.6	20.3	0.144	3.5	24.4	0.227	4.8	32.2	0.216
April	6.5	21.0	0.108	8.9	11.1	0.041	7.1	14.6	0.068	7.7	18.9	0.082	6.1	40.7	0.224
May	13.6	36.6	0.087	12.1	22.7	0.061	11.1	18.8	0.054	14.0	26.0	0.060	12.3	28.7	0.075
June	16.2	44.3	0.091	15.0	24.7	0.055	14.2	24.6	0.058	16.6	64.1	0.129	16.0	78.2	0.163
July	18.2	45.9	0.081	20.1	27.0	0.043	17.1	31.9	0.060	17.8	137.7	0.250	16.6	161.5	0.314
August	18.0	45.4	0.081	17.0	46.2	0.087	19.6	14.8	0.024	17.0	128.4	0.244	17.6	107.1	0.197
September	12.6	41.2	0.109	14.5	21.6	0.050	14.1	76.1	0.180	15.3	36.0	0.078	13.7	82.4	0.201
October	10.1	37.6	0.119	10.5	17.2	0.053	7.8	47.2	0.196	8.0	70.8	0.286	10.7	106.1	0.318
November	5.3	24.0	0.151	5.4	7.6	0.047	6.2	43.9	0.237	3.7	60.0	0.540	5.4	73.3	0.454
December	3.4	78.4	0.745	1.3	56.9	1.397	5.2	29.0	0.180	2.7	50.6	0.608	2.7	76.0	0.909
yearly	8.4	460.8	0.151	9.3	279.1	0.082	9.2	356.8	0.106	8.9	687.4	0.211	8.8	865.6	0.270

2.3. Experimental Design

Two experimental mid-forest meadows were established on two adjacent sites, located approximately 0.5 km apart. At these sites, each of the experimental treatments was established on an area of approximately 0.3 hectares. Such large areas were necessary to carry out the tested renovation methods using the full-scale machines available at the Forest Wildlife Breeding Centre. We also intended to check the feasibility of the applied renovation methods in practice. Two experimental mid-forest meadows were defined in the article as follows:

- Object no. 1—Wnęka eng. Niche (object W)—54°6′16.761″ N, 16°47′30.403″ E, av. elevation 117 m: The renovation of this mid-forest meadow began at the beginning of the growing season in 2014 (sown 09.04.2014). While the entire site covered approximately 5.5 hectares, it was only partially utilized for the experimental purpose with five treatments designated for the study in one replication, with five large plots/research areas created (ca. 0.3 ha each). The reason for such decision was the terrain relief of object W because only about 1.5 ha was located on a flat terrain as in the case of the second mid-forest meadow, and the remaining part was hilly, which could have influenced the emergence, growth, and development of plants after sowing due to different exposures to light. The sward botanical composition before renovation was dominated by *Dactylis glomerata* (48.9%), *Festuca arundinacea* (18.9%), *Festuca rubra* (7.6%), *Holcus mollis* (10.3%), and other dicotyledonous species of low nutritional value.

- Object no. 2—Topolowa Droga eng. Poplar Road (object TD)—54°6′5.925″ N, 16°46′55.418″ E, av. elevation 132 m: This mid-forest meadow underwent renovation in the beginning of autumn in 2013 (sown 28.09.2013). The entire object covered an area of 2.5 hectares and was fully adapted for the experiment. Within this meadow, four treatments were designated for this study, established randomly in two replications of approximately 0.3 hectares each (in total eight plots/research areas). The sward botanical composition before renovation was dominated by *Festuca rubra* (29.9%), *Dactylis glomerata* (14.2%), *Festuca arundinacea* (4.3%), *Sonchus arvensis* (4.0%), and other mono- and dicotyledonous species of low nutritional value.

The names of the objects (Wnęka and Topolowa Droga) are the common names of mid-forest meadows used in the Forest Wildlife Breeding Centre. Both objects are located on soils with a low class in the Polish Soil Classification system, indicating very poor agricultural suitability. These soils are typical brown soils with a granulometric composition dominated by sand with low fertility (Table 2). Light clays were present in part of object W, but this area was excluded from the experiment [32]. Overall, the habitats were defined by low nutrient content and limited water retention capacity. According to the Agricultural Drought Monitoring System [33], the entire area of object TD falls within the "very susceptible to drought" category (the weakest one). About 50% of object W's area is classified similarly, but due to the other environmental factors (slope, forest formation, altitude), the experiment was located on soils "susceptible to drought" .

Table 2. Basic soil parameters (average values) of two mid-forest meadows before establishment of experiments.

Parameter	Object W		Object TD	
	Content	Classification	Content	Classification
pH	5.02	acid	5.05	acid
Phosphorus (P_2O_5) (mg/100 g of soil)	10.80	moderate	14.65	moderate
Potassium (K_2O) (mg/100 g of soil)	7.00	low	7.00	low
Magnesium (mg/100 g of soil)	4.75	moderate	1.95	very low

On both objects, a comparison was conducted between control treatment (C), which did not undergo any renovation efforts, and treatments represented different renovation techniques. We tested the following methods:

- Overdrilling using seeds of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) (O): The overseeding technique included harrowing, which was used for sod preparation; then, the seeds in the rate of 20 kg/ha were sown using the Väderstad Rapid 300s Super XL seeder followed by rolling.
- Full tillage usage for sowing the three types of seed mixtures M1, M2, and M3 (detailed composition is given in Table 3): The full tillage technique included ploughing, then the harrowing operation for seedbed preparation and sowing seeds in the rate of 40 kg/ha using the Väderstad Rapid 300s Super XL seeder, followed by rolling. Additionally, cleaning cut was performed 6 weeks after sowing to prevent weed infestation.

Mixtures M1 and M2 were commercially available, and M3 was used by the authors for experimental purposes. Due to areas of both mid-forest meadow and seed mixture availability, the experimental design differed between the objects: TD included treatments C, O, M2, and M3 in two repetitions, and W included treatments C, O, M1, M2, and M3 in one repetition.

Both mid-forest meadows were previously utilized by the Forest Wildlife Breeding Centre as foraging areas for wildlife. The management schedule included fertilization with an application of 9 kg/ha of nitrogen, 30 kg/ha of phosphorus, and 45 kg/ha of potassium at the beginning of each growing season. The areas were grazed mainly by the free-living red deer population. The remaining non-grazed part of the sward was regularly mowed both in the beginning of summer and at the end of the growing season in autumn. The sward yield obtained from the mowing was subsequently conserved in the form of hay.

Table 3. List of seed mixture species used for renovation of mid-forest meadows.

Seed Mixture	Species Composition
M1	*Brassica rapa* subsp. *rapa*, *Fagopyrum* sp., *Festuca pratensis*, *Lolium perenne*, *Ornithopus* sp., *Phacelia* sp., *Phleum pratense*, *Raphanus sativus*, *Secale cereale* var. *multicaule*, *Sinapis alba*, *Trifolium alexandrinum*, *Trifolium incarnatum*, *Trifolium pratense*, *Trifolium repens*, *Trifolium resupinatum*
M2	*Carum carvi*, *Cichorium intybus*, *Daucus carota*, *Festuca arundinacea*, *Festuca pratensis*, *Festuca rubra*, *Lolium perenne*, *Lotus corniculatus*, *Medicago lupulina*, *Medicago sativa*, *Phleum pratense*, *Plantago lanceolata*, *Poa pratensis*, *Sanguisorba minor*, *Trifolium alexandrinum*, *Trifolium hybridum*, *Trifolium pratense*, *Trifolium repens*
M3	*Achillea millefolium*, *Arrhenatherum elatius*, *Carum carvi*, *Cichorium intybus*, *Dactylis glomerata*, *Daucus carota*, *Festuca arundinacea*, *Festuca pratensis*, *Foeniculum vulgare*, *Galium verum*, *Lolium perenne*, *Lotus corniculatus*, *Medicago sativa*, *Petroselinum crispum*, *Phleum pratense*, *Pimpinella saxifraga*, *Plantago lanceolata*, *Poa pratensis*, *Sanguisorba officinalis*, *Trifolium hybridum*, *Trifolium pratense*, *Trifolium repens*

For eliminating the impact of animals on the sward, three 2 m × 2 m wire mesh grazing exclusion cages were placed on every experimental treatment. Grazing exclusion cages were used for the estimation of forage accumulation, which is a key response in grazing experiments on continuously stocked pastures. The management of experimental areas did not differ between the ungrazed area (exclusion cages) and grazed area, which was available for animals. The grazing exclusion cages were dismounted during the mowing events and removed with each growing season. The location of the grazing exclusion cages within the treatment areas was randomly changed during the following experimental years. This made it possible to carry out analyses on ungrazed and grazed areas.

2.4. Methods

For the assessment of habitat conditions, in which the effectiveness of the mid-forest meadows renovation was tested, soil moisture analysis was conducted using an ML3 ThetaProbe connected to an HH2 reader (Delta-T Devices Ltd., Burwell, UK). The device was configured with standard settings for mineral soil analysis (root depth—50 mm; field capacity—0.380 m^3/m). Measurements were conducted on designated dates approximately every two weeks, from the beginning of April to the end of October in each study year between 2014 and 2017. Data were collected from six locations within each area. Additionally, on the same dates and similar regime of data collecting, the vitality of the sward dominant species was determined to assess the fertility of the habitat. The Soil Plant Analyses Development (SPAD) index, as a greenness indicator, correlated with the nitrogen status in plants recorded using Minolta SPAD-502Plus (Konica Minolta Optics, Tokyo, Japan) with standard settings. Due to the natural occurrence on all treatments, *Dactylis glomerata* was selected as the representative species.

Analysis of sward botanical composition was based on the yield proportion method [37]. The sward samples, collected from each grazing exclusion cages using a square metal frame with three subsamples per cage (9 subsamples per plot per date), were separated into individual species, dried, and weighed. Based on the relation between the weight of each species to the total DM yield of the samples, the botanical composition was assessed. To unify the results between the experimental treatments, the individual results were summarized and presented as the proportion of plant functional groups (grasses, herbs, legumes).

Assessing the sward productivity of each treatment was based on the amount of sward biomass collected from the grazing exclusion cages (without grazing pressure). The timing of these assessments was synchronized with the standard management schedule for mid-forest meadows within the Polanów Forest District. In particular, sward harvest for hay production were conducted in June and October, before the end of the growing season. Sward samples were manually cut at an approximate height level of 5 cm from the ground within the area of each grazing exclusion cage (in 3 repetitions) using a square meter frame (0.5 m × 0.5 m) (9 repetitions per area per date). The collected herbage was dried in an oven at 60°C for 48 h for dry matter (DM) content determination. Based on the collected fresh biomass amount and DM content in the sward, the DM yield of each treatment (in kg DM per ha) was estimated.

The herbage quality of the renovated mid-forest meadows was evaluated using Wendee proximal feed ingredient analysis [38] and dry matter digestibility (DMD). The analysis of the five basic components of dry matter for evaluation of nutritive value of forage (ash, crude protein (CP), ether extract (EE), crude fiber (CF), nitrogen-free extract (NFE)) was performed using near-infrared reflectance spectroscopy (NIRS) utilizing the FOSS DS 2500 Analyzer (Foss NIR Systems, Laurel, MD, USA). Sward samples from each experimental treatment were collected from grazing exclusion cages during the yield quantity sampling (covering all collection dates) and were prepared in accordance with the laboratory's guidelines. The preparation protocol involved drying, grinding, and thoroughly mixing the samples, ensuring each had a minimum weight of 100 g. The dried samples taken during the period of investigations were then sent to the laboratory in two batches, one in 2015 and another in 2017. DMD was assessed in relation to acid detergent fibers (ADF) using the equation proposed by Di Marco [39].

2.5. Statistical Analysis

The normality of the collected data was assessed using the Shapiro–Wilk test. Due to the instability of some of the habitat parameters, the Interquartile Range (IQR) method was used to detect and remove outliers from the data. Given the non-normal distribution of most data obtained from all experiments, the significance of differences between renovation methods was estimated using the Kruskal–Wallis test (one-way ANOVA on ranks). The statistical analysis was conducted using R Statistical Software (ver. 4.3.0) with the Agricolae package (function kruskal()). Groups that were statistically different were distinguished by a multiple comparisons test of rank sums, which is conceptually similar to Nemenyi's post hoc test, and adjustments for multiple comparisons were made using critical values derived from rank distribution tables. Both procedures were applied within the used function.

3. Results

3.1. Soil Moisture and Vitality of the Sward

In the study of the effectiveness of the mid-forest meadow renovation, the habitat conditions are very important. Therefore, the soil moisture content and vitality of the sward as an indicator of soil fertility were analyzed. The data of soil moisture content did not show notable differences between the treatments within each experimental object. However, considerable variations (p-value < 0.01) were noted between the renovated mid-forest meadows (Figure 1). Throughout the experimental years, superior habitat conditions, in terms of soil moisture content, were consistently identified at object W. On average, a soil moisture level of 20.38% of the volume water capacity was recorded, representing approximately 25% more compared to the object TD, with an average volume of 16.24%. The disparities in soil moisture levels between the two mid-forest meadows ranged between 16% and 37% in the subsequent years of the experiment, with the higher value consistently recorded at object W (Table 4).

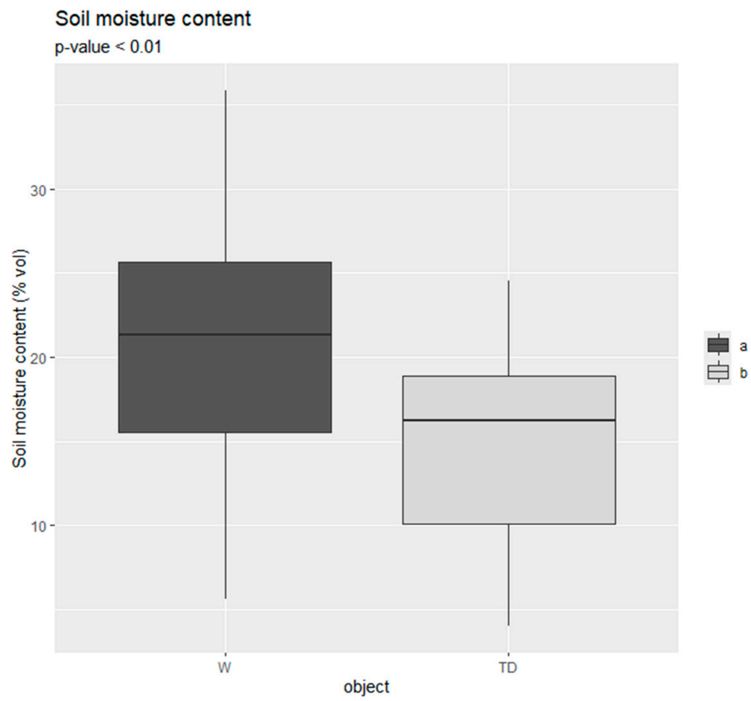

Figure 1. Comparison of two experimental mid-forest meadows in regard to soil moisture content. (a, b—different letters indicate statistically significant difference between mid-forest meadows).

Table 4. Soil moisture content in two experimental mid-forest meadows in the study years 2014–2017.

Object	%vol	Year			
		2014	2015	2016	2017
W	mean ± sd	20.46 ± 2.49	15.24 ± 7.19	18.81 ± 6.84	22.45 ± 6.78
	minimum	17.62	6.10	5.58	9.83
	maximum	24.36	26.6	29.50	35.83
TD	mean ± sd	16.47 ± 1.73	11.79 ± 6.06	15.78 ± 5.53	14.02 ± 4.75
	minimum	13.51	4.30	4.02	5.42
	maximum	20.28	18.7	24.5	21.32

On object W, the highest annual average soil moisture content was noticed in 2017 (22.45% vol, with a maximum record of 35.83% vol). The lowest level was observed in 2016 (18.81% vol, with a minimum of 5.58% vol). Conversely, on object TD, the highest annual average soil moisture level was recorded in 2014 (16.47% vol), while the highest individual record was noted in 2016 (24.50% vol). The lowest level was observed in 2015 (11.79% vol), and the minimum individual record was also noted in 2016 (4.02% vol).

Taking into consideration *Dactylis glomerata* as a species indicating the fertility of the soil, it turned out that the results from the Shapiro–Wilk test indicated a normal distribution of the SPAD index data (p-value = *0.1996*). However, to maintain methodological uniformity across all analyses, a non-parametric test was employed. While no significant differences were found within individual experimental areas, notable disparities surfaced when comparing results across entire mid-forest meadows. Similar to the findings in the soil moisture analysis, the SPAD index consistently demonstrated higher values for object W compared to object TD. The average SPAD index value for object W was 398.15, representing a 13% increase over object TD's average of 344.45 (Figure 2).

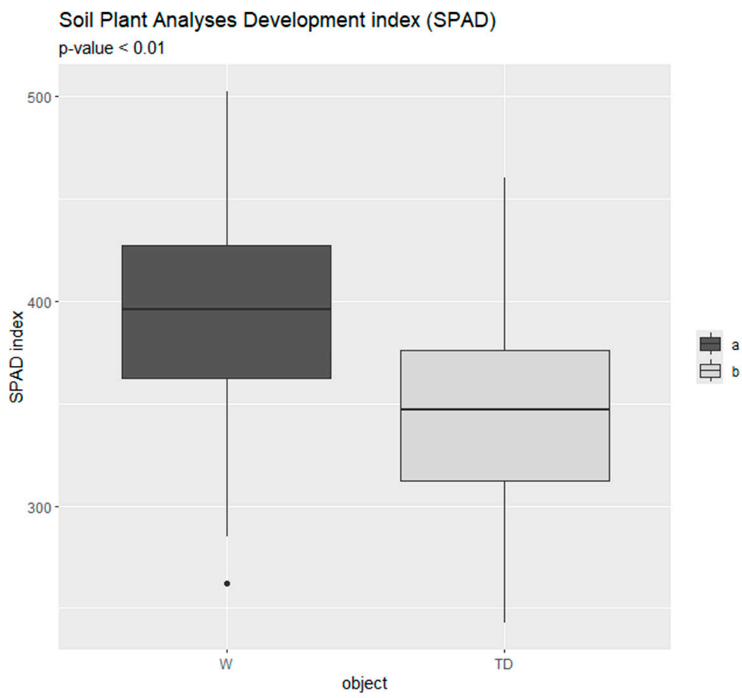

Figure 2. Comparison of two experimental mid-forest meadows in regard to SPAD (Soil Plant Analyses Development) index of *Dactylis glomerata* as the representative species (a, b—different letters indicate statistically significant difference between mid-forest meadows).

These variations between the two objects ranged from 5% to 17% over subsequent experimental years (Table 5). In both meadows, the highest yearly SPAD index values were recorded in 2017 (W = 417.1, TD = 350.6), while the lowest SPAD index values were observed in 2015 (W = 341.0, TD = 322.8). The peak individual SPAD index value for object W was recorded in 2017 (502.0), whereas for object TD, it was in 2016 (460.0). The lowest individual SPAD index values for object TD (243.0) and object W (262.0) were both recorded in 2015. A lower SPAD value of *Dactylis glomerata* correlates with the low fertility of the soil, insufficient plant nitrogen nutrition, and their lower suitability for obtaining a high DM yield.

Table 5. SPAD (Soil Plant Analyses Development) index of Dactylis glomerata in two experimental mid-forest meadows in the study years from 2014 to 2017.

Object	SPAD Index	Year			
		2014	2015	2016	2017
W	mean ± sd	369 ± 39	341 ± 51	386 ± 42	417 ± 47
	minimum	323	262	285	322
	maximum	412	431	468	502
TD	mean ± sd	345 ± 31	323 ± 49	345 ± 47	351 ± 44
	minimum	287	243	261	247
	maximum	395	400	460	430

As both soil moisture and SPAD index analyses revealed no significant differences between areas within the same object but showed significant differences between the two mid-forest meadows, the remaining results were analyzed separately for each object.

3.2. Sward Botanical Composition

After the renovation of mid-forest meadows, the differences between experimental treatments were significant and differed during study years (Table 6, Figure 3). On object W, the most significant difference in plant composition was observed in the treatments that underwent full tillage renovation. In the first year of the study, grasses made up 70%

(M1) to 72.5% (M3) of the collected biomass, while herbs accounted for 8.5% (M1) to 11% (M3) and legumes ranged from 11.5% (M3) to 16% (M1). However, in the subsequent years, this diversity waned, diversity decreased, and grasses dominated by the end of the study period. The M3 treatment maintained a slightly higher diversity than M1 and coM2, with a more significant proportion of herbs and legumes. The control and overdrilled treatments had a more stable percentage of grasses throughout the study period. Overdrilling resulted in a higher percentage of legumes (7%) in the first year, but this number decreased in the following years.

Table 6. Sward botanical composition of mid-forest meadow on object W in terms of functional group of plants depending on renovation method and applied mixture in the years of 2015–2017 (%).

Treatment [1]	2015				2016				2017			
	[2] G	[3] H	[4] L	[5] W	[2] G	[3] H	[4] L	[5] W	[2] G	[3] H	[4] L	[5] W
					I cut							
[1] C	84.0	0.0	3.0	13.0	90.0	4.0	2.0	4.0	90.3	1.0	2.7	6.0
O	81.0	2.0	14.0	3.0	98.0	0.0	0.0	2.0	90.7	1.3	6.0	2.0
M1	58.0	15.0	22.0	5.0	88.0	1.0	9.0	2.0	93.8	0.7	5.5	0.0
M2	62.0	15.0	20.0	3.0	100.0	0.0	0.0	0.0	89.2	1.3	7.8	1.7
M3	65.0	9.0	20.0	6.0	92.0	4.0	3.0	1.0	82.0	8.7	9.0	0.3
					II cut							
C	85.0	3.0	4.0	8.0	87.0	1.0	4.0	8.0	99.3	0.0	0.0	0.7
O	90.0	4.0	0.0	6.0	98.0	0.0	0.0	2.0	91.2	2.3	0.5	6.0
M1	83.0	2.0	10.0	5.0	86.0	2.0	10.0	2.0	100.0	0.0	0.0	0.0
M2	82.0	7.0	7.0	4.0	100.0	0.0	0.0	0.0	99.3	0.3	0.3	0.0
M3	80.0	10.0	3.0	7.0	96.0	2.0	2.0	0.0	95.4	3.7	0.9	0.0

[1] C—control, no renovation; O—overdrilling; M1—full tillage + M1 mixture; M2—full tillage + M2 mixture; M3—full tillage + M2 mixture; [2] G—grasses; [3] H—herbs; [4] L—legumes; [5] W—weeds.

Figure 3. Sward botanical composition of mid-forest meadow on object W given as averages for growing season in terms of functional group of plants depending on renovation method and applied mixture in the years 2015–2017 (%)—explanations as in Table 6.

All renovation methods had a positive effect on weed proportions (such as *Cirsium arvense*, *Cerastium arvense*, or *Erigeron canadensis*) in the collected biomass in comparison to the control. During the first growing season, weed content ranged from 3.5 to 6.5% (control—10.5%) and successively decreased in 2016. In the last year of the experiment, on the full tillage treatments, the weed content was less than 1%, while the overdrilled treatment resulted in the same as the control.

More challenging habitat conditions on object TD caused a different situation with the sward composition, without trends in the proportions of different groups (Table 7, Figure 4). The control showed a steady presence of grasses, with fluctuations between the herb and weed groups. The overdrilled area demonstrated a notable increase in weeds, which suggests the changes connected to environmental factors. Full renovation, including sowing mixtures M2 and M3, also caused the stable level of grass proportions to range from 60 to 70% in the subsequent years. The presence of legumes was the changing factor, which decreased more in the case of mixture M3 (7.3% to 1.9%). Also, a stable content of herbs (*Plantago lanceolata* and *Achillea millefolium* mostly) was noticeable.

The renovation did not affect the occurrence of weed species. In 2014 and 2015, the highest weed share was observed on treatments with full tillage, while in 2016, it was observed on the control and overdrilling groups. This group was represented mainly by *Taraxacum officinale*, which due to the growth characteristics, overpowered other species in the samples if it occurred.

Table 7. Sward botanical composition of mid-forest meadow object TD with regard to functional group of plants depending on renovation method and applied mixture in the years of 2014–2016 (%).

Treatment [1]	2014				2015				2016			
	[2] G	[3] H	[4] L	[5] W	[2] G	[3] H	[4] L	[5] W	[2] G	[3] H	[4] L	[5] W
					I cut							
[1] C	86.5	7.0	2.0	4.5	85.0	13.0	0.5	1.5	70.0	5.5	3.3	21.2
O	86.5	7.0	2.0	4.5	92.0	4.0	2.5	1.5	44.7	9.2	1.0	44.7
M2	43.0	7.0	13.0	37.0	47.0	7.0	9.5	36.5	72.3	16.2	0.0	11.2
M3	57.0	10.0	11.5	21.5	53.0	7.5	8.5	31.0	62.7	29.5	3.7	4.2
					II cut							
C	86.0	10.5	2.0	1.5	83.5	10.5	0.0	6.0	79.0	3.5	1.0	16.5
O	83.0	13.5	3.0	0.5	75.0	6.0	2.0	17.0	87.5	0.5	0.0	12.0
M2	72.0	19.0	9.0	0.0	77.5	10.5	0.0	12.0	88.5	2.0	7.0	2.5
M3	81.5	10.5	8.0	0.0	74.0	10.5	1.0	14.5	73.5	6.0	14.0	6.5

[1] C—control, no renovation; O—overdrilling; M2—full tillage + M2 mixture; M3—full tillage + M2 mixture; [2] G—grasses; [3] H—herbs; [4] L—legumes; [5] W—weeds.

Figure 4. Sward botanical composition of mid-forest meadow on object TD given as averages for growing season in terms of functional group of plants depending on renovation method and applied mixture in the years of 2014–2016 (%)—explanations provided in Table 7.

3.3. Sward Yield

On object W, all renovation methods exhibited significant differences from one another (Table 8 and Figure 5). The highest dry matter yield performance was recorded on the area with mixture M2, with an average total yield of 6712 kg/ha. The M3 mixture demonstrated a slightly lower, yet substantial, average total yield of 6415 kg/ha. It is noteworthy that both mixtures yielded comparable results throughout the experiment. Initially, the M1 mixture recorded the highest yield, exceeding 9000 kg/ha in the first year. However, subsequent years saw a sharp decline in sward yield, culminating in a total average yield of 6153 kg/ha for the entire experiment. On average, overdrilling yielded less than the full tillage treatment but was still significantly higher than the control (4459 kg/ha vs. 3853 kg/ha, respectively). During the growing season, the highest yields were harvested in the first cut, regardless of the treatment, from 64.6 to 83.5% of the total yield in the years of this study. The highest share of yield in the second cut was recorded in 2016, in which the total yield was the lowest, regardless of the treatment. This was certainly related to the notably lower VCI values in the April–June period. The most stable dynamics of the yield development during the growing season were distinguished by the M3 mixture, in which, in 2016–2017, the proportion between the first and second cut was 60:40.

Table 8. Dry matter yield of mid-forest meadow on object W depending on renovation method and applied mixture in the years of 2015–2017 (kg/ha DM) (different letters indicate statistically significant differences between renovation method and applied mixture).

Treatment [1]	2015						2016						2017					
	Cut I		Cut II		Total		Cut I		Cut II		Total		Cut I		Cut II		Total	
[1] C	3488	a	799	c	4287	a	2086	b	1287	a	3372	bc	3193	ab	707	c	3900	b
O	5797	a	753	c	6551	a	2400	b	1204	a	3604	c	2526	b	695	c	3221	b
M1	7653	a	1443	ab	9096	a	2998	ab	1576	a	4574	ab	3165	ab	1625	b	4790	b
M2	6033	a	1520	a	7553	a	3664	a	1757	a	5421	a	5686	a	1476	b	7161	a
M3	5928	a	1208	b	7136	a	2776	ab	1804	a	4580	ab	4571	ab	2958	a	7529	a
p-value	*0.5747*		*0.0192*		*0.4290*		*0.1088*		*0.2579*		*0.0526*		*0.1241*		*0.0162*		*0.0221*	

[1] C—control, no renovation; O—overdrilling; M1—full tillage + M1 mixture; M2—full tillage + M2 mixture; M3—full tillage + M3 mixture.

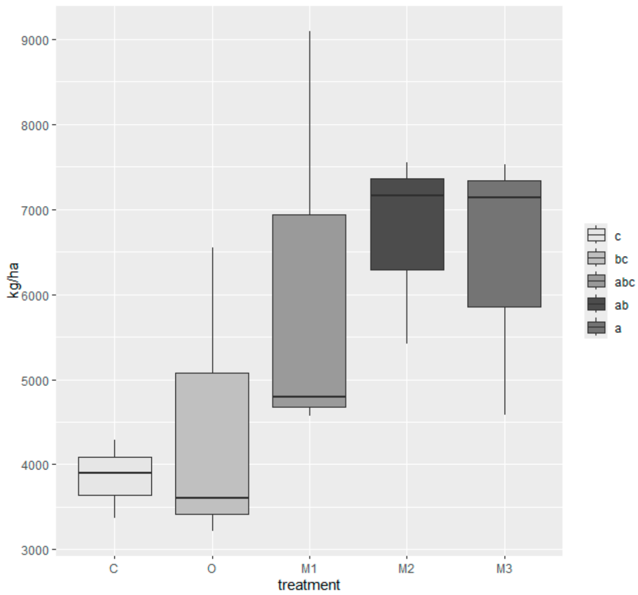

Figure 5. Total dry matter yield of mid-forest meadow on object W depending on renovation method and applied mixture in the years of 2015–2017 (kg/ha DM)—explanations provided in Table 8 (different letters indicate statistically significant differences between renovation method and applied mixture).

The different environmental conditions were observed in object TD (Table 9 and Figure 6). In particular, the patchiness of the habitat caused a broader range of data; thus, the statistical test did not indicate significant differences between the total mean results of all treatments. Specifically, the M2 had an average total yield of 3691 kg/ha, while the M3 had a lower yield, averaging 2995 kg/ha. The overdrilling at object TD yielded lower than the control, with yields of 2224 kg/ha and 2840 kg/ha, respectively. This trend was observed during the whole experiment. The low yield of the overdrilling was certainly caused by the response of overdrilled *Lolium perenne* and *Trifolium repens* (shallow-rooting species) to water deficits in the topsoil, especially in spring during the study years. In general, the treatments subjected to renovation were distinguished by a higher share of second cuts in the total annual yield in this study years compared to the control.

Table 9. Dry matter yield of mid-forest meadow on object TD depending on renovation method and applied mixture in the years of 2014–2016 (kg/ha DM) (different letters indicate statistically significant differences between renovation method and applied mixture).

Treatment [1]	2014						2015						2016					
	Cut I		Cut II		Total		Cut I		Cut II		Total		Cut I		Cut II		Total	
[1] C	2419	ab	860	a	3279	ab	2494	ab	712	b	3206	a	1363	a	672	a	2035	ab
O	1873	b	1070	a	2943	b	1603	b	614	b	2217	b	942	a	569	a	1511	b
M2	2829	a	1157	a	3986	ab	3462	ab	1269	a	4731	a	1480	a	875	a	2355	a
M3	1730	b	1078	a	2808	b	2253	ab	1278	a	3531	a	1866	a	780	a	2646	a
p-value	*0.0903*		*0.2907*		*0.0789*		*0.0682*		*0.0029*		*0.0153*		*0.2420*		*0.1634*		*0.1335*	

[1] C—control, no renovation; O—overdrilling; M2—full tillage + M2 mixture; M3—full tillage + M3 mixture.

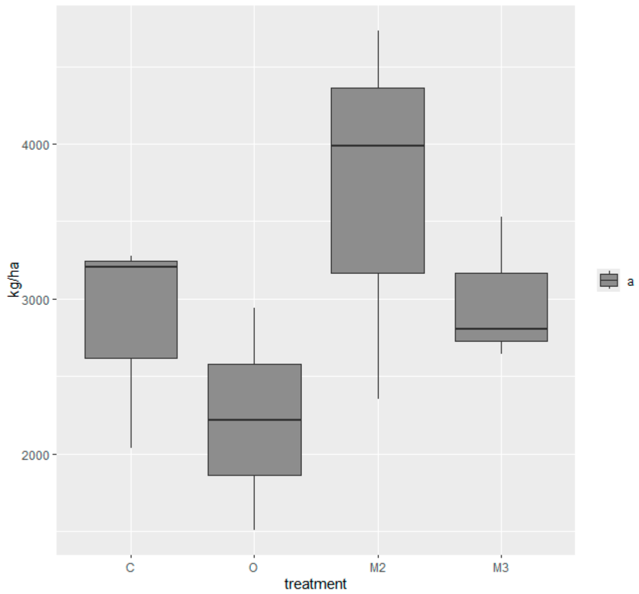

Figure 6. Total dry matter yield of mid-forest meadow on object TD depending on renovation method and applied mixture in the years of 2014–2016 (kg/ha DM)—explanations provided in Table 9 (different letters indicate statistically significant differences between renovation method and applied mixture).

3.4. Herbage Quality

3.4.1. Chemical Analysis

Based on the Weende proximal feed ingredient analysis, it appeared that the renovation had an impact on the herbage quality at the mid-forest meadows (Tables 10 and 11). The variations in most parameters had a visible and, in the case of several nutrients, a significant effect. In general, the renovation of mid-forest meadows using overdrilling did not significantly improve the quality of herbage compared to the control without renovation. Higher differences in herbage quality were estimated only after the application of the full tillage method using different mixtures.

Table 10. Chemical analysis of herbage from mid-forest meadow on object W depending on renovation method and applied mixture in the years of 2015–2017 (g/kg DM, average values) (different letters indicate statistically significant differences between renovation method and applied mixture).

Treatment [1]	Ash		Crude Protein		Ether Extract		Crude Fiber		Nitrogen-Free Extract	
[1] C	66.8	a	82.8	d	24.2	a	336.8	a	489.4	ab
O	69.4	a	84.6	cd	25.2	a	320.8	a	500	a
M1	70.8	a	100.2	ab	24.8	a	312.4	a	471.6	bc
M2	64.8	a	134.2	bc	25.4	a	303.4	a	486.2	ab
M3	70.4	a	140.6	a	24.4	a	307.4	a	457.2	c
p-value	*0.9149*		*0.0066*		*0.9576*		*0.3915*		*0.0354*	

[1] C—control, no renovation; O—overdrilling; M1—full tillage + M1 mixture; M2—full tillage + M2 mixture; M3—full tillage + M3 mixture;.

Table 11. Chemical analysis of herbage from mid-forest meadow on object TD depending on renovation method and applied mixture in the years of 2014–2016 (g/kg DM, average values) (different letters indicate statistically significant differences between renovation method and applied mixture).

Treatment [1]	Ash		Crude Protein		Ether Extract		Crude Fiber		Nitrogen-Free Extract	
[1] C	59.3	b	119.7	b	27.8	b	286.0	a	507.2	a
O	60.7	b	121.2	b	28.2	b	282.5	a	509.2	a
M2	69.5	a	149.0	a	33.7	a	251.2	b	498.7	a
M3	68.5	a	151.5	a	32.8	a	252.5	b	496.3	a
p-value	*0.3973*		*0.1950*		*0.0327*		*0.4448*		*0.6705*	

[1] C—control, no renovation; O—overdrilling; M2—full tillage + M2 mixture; M3—full tillage + M3 mixture.

On object W, the highest CP content throughout the study period was determined in the herbage collected from the mid-forest meadow renovated using the full tillage method and sowing M3 mixture (Table 10). Similarly to the other treatments of the full tillage method with M1 and M2 mixtures, the CP content was significantly higher than the control and overdrilling treatments. When analyzing the CF content in the herbage, a decrease in this component in dry matter was found in the treatments with renovation compared to the control. The EE content in the herbage had limited variation; therefore, the differences between the treatments were not significant. It was similar in the case of ash. Differences in the NFE content in herbage were also observed, with a significant decrease in this component compared to the control in the full tillage method using M1 and M3 mixtures.

In the case of the TD object, the assessment of the chemical composition of the herbage harvested from the evaluated experimental treatments revealed significant differences in the content of ash, CP, EE, and CF, except for NFE (Table 11). The herbage from the treatments of full tillage using M2 and M3 mixtures were characterized by higher CP, ash, and EE and lower CF contents compared to the control and overdrilling treatments.

3.4.2. Dry Matter Digestibility

The second important element of herbage quality assessment, apart from the chemical composition of the dry matter yield, is dry matter digestibility. In Table 12, the results show the DMD of herbage from the mid-forest meadow depending on the renovation method and applied mixture during the investigation period. For object W, the DMD of herbage from renovated mid-forest meadows was higher in comparison to the herbage collected from the control treatment, but due to the range of data, the differences were not statistically confirmed. Similarly, at object TD, DMD values of herbage collected from full tillage treatments were higher, but the differences comparing to the control were very low and non-significant.

Table 12. Dry matter digestibility (DMD) of herbage from mid-forest meadow depending on renovation method and applied mixture during investigation period (%, average values) (different letters indicate statistically significant differences between renovation method and applied mixture).

Treatment [1]	Object W		Object TD	
[1] C	56.2	a	59.7	a
O	57.9	a	58.6	a
M1	57.1	a	-	-
M2	58.0	a	60.6	a
M3	57.4	a	60.1	a
p-value	*0.9447*		*0.9470*	

[1] C—control, no renovation; O—overdrilling; M1—full tillage + M1 mixture; M2—full tillage + M2 mixture; M3—full tillage + M3 mixture.

4. Discussion

The objective of this study was to evaluate the most effective way to renovate the mid-forest meadows in terms of productivity. Environmental conditions noticeably influenced the experimental results observed at both meadows. Nevertheless, both sites presented challenging conditions, characterized by sandy soils, variable weather patterns, and unfavorable ecotone factors such as shading and uneven soil moisture levels due to the adjacent forest areas. In such conditions, two experiments were conducted in which different methods of renovation of mid-forest meadows were analyzed: overdrilling and full tillage methods using three mixtures with different botanical composition (M1, M2, and M3). In the research approach, it was very important to locate the experiments in the real habitat of mid-forest meadows, which are used by the free-living deer population.

Soil moisture stands out as a crucial factor influencing the potential success of grassland renovation and can be a strong predictor of meadow productivity [40–42]. Grasslands are more tolerant of excessive water supply [43] but are also more vulnerable to droughts compared to other ecosystems due to the shallow root system of most grasses. The availability of water is intricately linked to the quality and quantity of biomass produced, especially in short-term analyses [44,45], and water deficits can cause annual variations in yield. Soil structure, nutrient availability, and habitat patchiness show a direct correlation with soil water content [46]. The ecosystemic interplay of soil, microbes, and plants is directly reflected in forage quantity and quality [18,47–49]. These relationships played an important role on the sites where the experiments were conducted. As indicated in Figure 1, more difficult habitat conditions occurred on the object TD than on object W. Nevertheless, as a result of the renovation of the mid-forest meadows, satisfactory effects were obtained, measured by dry matter yield and herbage quality.

The habitat quality was also evident in the plant leaf greenness, as assessed using the SPAD index of *Dactylis glomerata* as the representative species, because of its presence in the botanical composition of all analyzed swards. This parameter served to describe the overall vitality of the sward and the plant vigor [50]. In controlled conditions, during the pot experiments, changing the level of soil water deficit caused the growth of the index in *Dactylis glomerata* [50,51]. However, in field experiments, where environmental factors cannot be controlled, the SPAD level reflects the outcome of the more complex soil–plant feedback. As the leaf greenness is strictly attached to the chlorophyll content, the SPAD level can describe the photosynthetic capacity, as well as nitrogen content in the plant [52]. Environmental factors influence the pigment composition in the plant tissues, making the SPAD index one of the key plant ecophysiological analyses [53]. In the performed experiments, the significantly lower SPAD index was determined in the object TD in comparison to object W (Figure 2). This poor condition also translated to the lower performance of the renovation methods, particularly at object TD, supporting the notion that site-specific factors play a crucial role in renovation success (49–52). The original sward's yield in both mid-forest meadows was significantly influenced by habitat conditions. The total yield from control area in most experimental years, with the exception of object W in 2015, fell below the average for permanent meadows in Poland [54]. On the other hand, mid-forest meadows are often located in less agriculturally valuable areas in the point of view of its soil fertility; hence, the obtained level of productivity should be assessed as satisfactory.

Overdrilling with *Lolium perenne* and *Trifolium repens*, chosen as an easy method to improve sward botanical composition, did not influence sward performance under the analyzed conditions. This underperformance is evident in the biomass produced, as the overdrilling treatment generally yielded slightly less than the control at both experimental objects. Furthermore, the limited representation of legumes each year suggests that the "new" seeds were outcompeted by the existing sward. The poor results of overdrilling the forest meadows at both sites were also due to difficult habitat conditions, especially soil moisture shortages in some periods, which turned out to be crucial for introducing valuable species to the existing turf.

The characteristics of the habitat patches directly impacted the survival and establishment of new plant species within the existing vegetation [55–57]. Theoretically, better effects of the overseeding method were obtained on mineral soils [58], but plant diversity, weed control, and overall performance remained unaffected by this technique, likely due to the persistence of existing vegetation and competition from established grasses [48,59,60]. The lack of effects on yield quality or botanical composition suggests that habitat factors played a pivotal role, and increasing the seeding rate of any species used would not significantly affect the results [61] or planting depth [62]. Some studies suggested that the grazing can reduce sward competition [55,63], but for mid-forest meadows used as forage for the red deer population, such factors were insufficient to reduce competition.

The findings suggested that without additional measures, such as soil aeration techniques and targeted herbicide application, coupled with proper post-sowing care [21,64–66], overdrilling may have limited success in mid-forest meadow renovation. However, adding such operations would limit the main advantages of this procedure—the cost-effectiveness and minimalization of soil structure damages [67].

The full tillage method effectively removed competition from old sward plant components, facilitating the establishment of new seedbeds. This approach proved to be a successful renovation strategy by creating an environment favorable for the growth of desirable sown species, particularly legumes and grasses. These species are crucial for enhancing the productivity and forage's nutritional value [14,60,68]. Additionally, full tillage positively influenced species diversity on the areas [24,66]. Although all treatments remained grass-rich (more than 70% of biomass) [69], significant improvements in both yield quantity and quality were observed.

At object W, the highest overall yield was observed for the M3 mixture, followed by M2 and M1, with significant differences in yield quantities among all mixtures. Both M3 and M2 mixtures yielded sustainably throughout the experiment. In contrast, the M1 mixture, after an initial peak yield exceeding 9000 kg/ha, declined below the levels of the other two mixtures. This decline in M1 is attributed to a reduction in herbs (from 15% to 0.7%) and legumes (from 22% to 5.5%), changes not observed in the other mixtures. The performance loss was mainly due to heavy grazing pressure by wild red deer, which preferred this mixture in the first year of the experiment [70]. Such forager impact can significantly alter biomass flow, plant species composition, growth rate, and nutrient flow, potentially damaging promising swards [71]. The experimental areas were utilized as forage areas for game species without restricted access, considering this an environmental factor [72].

Additionally, object W consistently demonstrated higher productivity measured by dry matter yield for all mixtures compared to object TD. For mixture M2, object W's yield was 6712 kg/ha, almost double that of object TD's 3691 kg/ha. Similarly, for M3, object W's yield was 6415 kg/ha, more than double object TD's 2995 kg/ha. These differences highlight the impact of object-specific conditions on yield, with object W's more favorable environment (particularly soil moisture) supporting higher productivity.

Interestingly, while object W produced higher overall yields for both mixtures M2 and M3, object TD yielded forage with superior nutritional quality in several aspects. The forage from object TD exhibited higher crude protein (CP) and crude fat (EE) contents, lower crude fiber (CF) content, and slightly better dry matter digestibility. The impact of challenging environmental conditions, including the ecotone effect of tree canopies [73], on various yield quality parameters is not fully understood and varies among species. However, increased forage quality under stress is supported by the literature [74]. It appears that the functional group ratios in mixtures M2 and M3 responded better to stress factors (habitat, foraging, etc.) in mid-forest meadows. Additionally, the higher presence of weeds and herbs (e.g., *Taraxacum officinale*) can not only influence forage quality [12] but also complicate predictions about forage quality [75].

The notable effect of the full tillage method combined with sowing seed mixtures in enhancing both productivity and forage quality emphasizes the importance of selecting appropriate seed mixtures based on local conditions and desired forage outcomes [22]. This was supported by Galvin [57] who found that soil disturbance combined with the introduction of high-yield species significantly increases biomass production in semi-arid landscapes. The effectiveness of renovation techniques varies based on how they modify soil and plant interactions [76]. Full tillage often resets these interactions more completely than overdrilling, providing a more favorable environment for the establishment and growth of desired species.

5. Conclusions

In the process of the renovation of mid-forest meadows, full tillage combined with the selection of appropriate mixtures proved to be a much better method compared to overdrilling. As a result of renovating two experimental objects used in the Polanów Forest District as the foraging areas for the free-living red deer population using this method, the improved botanical composition of the sward and better dry matter yield and herbage quality were achieved. Among the three tested mixtures—M1 and M2 (commercially available) and M3 (formulated by the authors)—the M2 mixture showed the best DM yield over a three-year management period in both higher (object W) and lower (object TD) soil moisture habitats. In the assessment of herbage quality, the M2 and M3 mixtures used in the renovation using the full tillage method performed better compared to control and overdrilling treatments. They were distinguished by a statistically significantly higher protein content on both objects, as well as a higher ash and EE, and a lower CF content on the TD site. In the case of object W, significantly lower CF and NFE contents were confirmed in the herbage only in the case of M3. In the dry matter digestibility studies, higher values were found for all the applied renovation methods compared to the control area only in object W with better habitat conditions but were not statistically confirmed. The obtained results proved that the renovation of mid-forest meadows, particularly the full tillage method with the use of a mixture well-matched to the habitat, can be a good way to make this type of forage base more productive for free-living herbivorous animals, especially red deer.

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