ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol. Agricultura 16(2) 2017, 99–106
www.agricultura.acta.utp.edu.pl pISSN 1644-0625 eISSN 2300-8504

ORIGINAL PAPER

Received: 19.10.2016
Received in revised form: 26.05.2017
Accepted: 12.06.2017

THE EFFECT OF SWARD RENOVATION METHOD, FORAGE MIXTURE AND FERTILIZATION ON GRASSLAND YIELD ON SANDY SOIL

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ABSTRACT

Background. Grasslands are considered as valuable for biodiversity maintaining and provides a range of ecosystem services. Optimal growth of renovated grasslands is influenced both by properly selected methods of renovation and subsequent balanced utilisation. The aim of the presented study was to assess the effect of renovation method, forage mixture and mineral fertilization on initial development, species composition and yield of forage grasslands established on sandy soil.
Material and methods. The experiment was conducted at the Agricultural Experimental Station Swojec, which belongs to the Wroclaw University of Environmental and Life Science. Two renovation methods (overdrilling and full cultivation), three types of forage mixtures: pure grass (mixture I), grass with *Trifolium repens* (mixture II) and grass with *T. pratense* (mixture III), and four fertilization levels (0, 140 PK (40 P + 100 K), 220 NPK (80 N + 40 P +100 K), 300 NPK (160 N + 40 P + 100 K) were used as experimental factors.
Results. The largest participation in species composition of the first harvest in the period between 2010–2012 was from *Lolium perenne* and *Phleum pratense* under both renovation methods. Tall grass species reached an average of 47%, short grasses 24%, and legumes 29% of DM. The overdrilling method significantly increased the plant yield when compared to the full cultivation method. The application of phosphorus and potassium (140 PK) gave the highest yield. The highest yield was obtained in plots where overdrilling of mixtures of forage grasses with *T. pratense* (mixture III) that were fertilized with only phosphorus and potassium.
Conclusion. The results indicate, that the yield of the grassland is the higher, when overdrilling, as a method of sward renovation, addition of legumes to a grass mixture and the application of phosphorus--potassium fertilization was applied.

Key words: forage mixture, full cultivation, germination, overdrilling, species composition, *Trifolium*

INTRODUCTION

Grassland provide food for animals, protects soil from erosion, and watercourses from the effects of pollution and eutrophication (Primdahl *et al.*, 2010; Sullivan *et al*., 2010; Dragomir *et al*., 2012; Szymura *et al.*, 2016). A balanced utilization of properly used treatments provides for optimal growth of grasslands (Neill *et al.*, 2015). When properly managed, fertilized, and grazed or mowed, grassland sward is very economical, ecological and one of the most desirable ways of feeding livestock (Wolski, 1998; Tanneberger *et al*., 2009; Van Rensburg *et al*., 2009; Williams *et al*., 2009).

In Poland, according to data from the Central Statistical Office, there are about 3.2 million hectares of meadows and pastures. Additionally, the cultivation of forage mixtures on arable lands covers an area of

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c.a. 0.5 million ha. In a comparison of the period 1980–1990 with the years 2000–2002 the yield of grasslands had decreased from 6 to 4 t·ha^{-1} (Wolski, 2002).

Grassland productivity is a result of many factors such as proper adjustment of any treatment to habitat conditions and moisture conditions. Mineral fertilizers used in proper doses have a positive effect on the quantity and quality of grassland yield (Wolski, 2010).

In the case of intensive grassland management, particularly that conducted on sandy soils, a common practice is renovation of the sward at intervals of 5–10 years. Unfortunately, this practice causes environmental risks for the protection of groundwater (Seidel *et al*., 2009). When grassland is ploughed for renovation, mineralization of live and dead plant material and soil organic matter leads to an increased soil nitrogen content (Francis *et al*., 1992; Seidel *et al*., 2007). To minimize the impact of grasslands renovation on the environment the overdrilling method can be used as an effective way to improve grasslands productivity. This method is more efficient and less expensive than the full cultivation method because it involves cultivation only during the seeding operation. The sward is only partially disturbed and the resident vegetation is not destroyed, unless herbicides are used. It provides for effective sod renovation and prevents leaching of soils and nutrient loss. Germination and emergence of sod-sown seed is generally higher than in the case of surface-sown seed (Grabowski *et al*., 1996; Goliński, 1998; Kozłowski, 1998; Wolski, 2002; Pötsch *et al*., 2013).

Cultivation of pure grass mixtures gives a lower yield when compared with grass-legume mixtures in extensive cultivation, where low (80 kg N) or medium (160 kg N) levels of fertilization are used (Roberts *et al.*, 1998; Wolski, 2002). Most often the mixtures are composed of: *Lolium multiflorum* Lam., *L. perenne* L., *Festuca pratensis* Huds. and *Festulolium* spp., and among legumes: *T. pratense* and *T. repens* are used (Kessler and Lehmann, 1998; Roberts *et al.*, 1998; Wolski, 2002; Staniak, 2009). Grass-legume mixtures have a higher nutritional value and are an important component of plant associations, with high ecological and landscape value. Sowing grasses and legumes together enables better utilize of the available resources and reduces the impact of competition between plants. It also has a positive effect on the organic matter in the soils, microflora, and soil fauna development (Wolski, 1998; Wolski, 2002). In recent years legumes are being applied for pasture renovation, regardless of the intensity of usage (Frame, 2005). The optimal legume percentage in the harvested biomass is (30–40%), (Sanderson *et al.*, 2012).

The potential production of *T. repens* is lower than that for *L. perenne*, because the yield of the mixture decreases with an increasing proportion of *T. repens*., however, an increase of white clover in the mixture results in an energy increase of the mixture (Frame, 2005). Therefore, a determination of the best methods of sandy-soil grasslands renovation is highly desirable from both a commercial value and environmental protection perspective.

The aim of this study was to evaluate the impact of renovation method, forage mixture and mineral fertilization on initial development, species composition and yield of renovated grassland on sandy soil.

MATERIAL AND METHODS

An experiment was conducted at the ‘Swojec’ Agricultural Experimental Station in Wroclaw, Lower Silesia, Poland (17°08’ E; 51°06’ N). The experiment was established on fluvial soil developed on sand under loamy sand, IVb quality class. The soil reaction of the surface horizon was neutral (pH 6.8).

The experiment was three factorial, set according to the split-split-plot method with 3 replications. The applied factors were:

(A) method of renovation: A1 – full cultivation (ploughing, cultivating, sowing, rolling after sowing); A2 – overdrilling:

(B) type of mixtures: B1 – I mixture; B2 – II mixture; B3 – III mixture. The species composition of the mixtures is listed in Table 1;

(C) mineral fertilization: C1 – 0; C2 – 140 PK (40 P kg·ha^{-1} + 100 K kg·ha^{-1}); C3 – 220 NPK (80 N kg·ha^{-1} + 40 P kg·ha^{-1} + 100 K kg·ha^{-1}); C4 – 300 NPK (160 N kg·ha^{-1} + 40 P kg·ha^{-1} + 100 K kg·ha^{-1}).

Table 1. Species composition in percentage of used forage mixtures

Specification	Mix I	Mix II	Mix III
Festulolium braunii (Rich.) var. Lofa	15	–	–
Festuca pratensis Huds. var. Lipanther	30	30	20
Lolium multiflorum Lam. var. Mowester	10	10	10
Lolium perenne L. (2n) var. Gladio	15	20	20
Lolium perenne L. (4n) var. Verano	30	25	25
Phleum pratense L. var. Liglory	–	10	10
Trifolium pratense L. var. Nike	–	–	15
Trifolium repens L. var. Grasslands Huia	–	5	–

The main plot was the method of renovation, where sub plots with different types of mixtures and then levels of mineral fertilisation were placed.

Full cultivation and overdrilling were carried out in spring 2010. An Overseeder with Double-Disc System was used for the overdrilling. The pairs of discs had a row distance of 7.5 cm and an overall working width of 130 cm. The seeds were sown to a depth of 1.0–1.5 cm. No herbicides were used. Forage mixtures with a standard sowing rate of 45 $kg \cdot ha^{-1}$ were used under both methods. Where applicable phosphorus fertilization was applied once in spring, nitrogen and potassium in three doses: in spring and after the first and the second harvest. The experiment was conducted for 3 years. The meadow sward was mowed to a 5 cm height, three times per year, in the middle of May, July and September, and each plot size was 10.2 m^2.

In the growing seasons (from April to October) the average annual sum of precipitation was 494.14mm, while the average temperature for the years 2010–2012 was 14.9°C. Overall, the weather conditions during the study period were favourable. The analysed sward had a good overwintering during the years of the experiment.

Seedling density per running meter was calculated four weeks after sowing. Species composition of the sward and percentage plant cover were identified before each harvest. A sample (0.5 kg) of green mass for the botanical-weighting analyses was taken from each plot and for each harvest in the period between 2010-2012. Similarly, the yield of green mass from each plot and each harvest was determined and the annual average yield was calculated. The biomass was sampled on 1 m^2 plots, and the sum of biomass from all three harvests in subsequent years, as well as the overall average for 2010–2012 was calculated.

The results were statistically analysed by the Anova model for split-split-plot design (Gomez and Gomez, 1984). All calculations were done on data obtained in the years 2010–2012 (basing on averages for the three-year period). The Newman-Keuls test with calculated critical ranges, as the post-hoc test was used (Steel *et al.*, 1997). All the computations were done using functions ‘ssp.plot’ and ‘SNK.test’ in ‘agricolae’ package (de Mendiburu, 2016) for R environment, at significance level $\alpha \leq 0.05$.

RESULTS

Seedling density per running meter after four weeks was significantly higher (F = 102.07, p = 0.000) in plots where full cultivation was used (average 100 seedlings) as compared to where overdrilling was used (average 55 seedlings). Taking into consideration the type of mixture, the average seedling density under both methods of cultivation was significantly higher on plots where the pure grass mixture was used (97 seedlings), comparing to legume-grass mixtures (73 for mixture II and 64 for mixture III), (F = 32.31, p = 0.000), for simplification detailed results of post--hoc tests are not shown.

Species composition of the sward from the first harvest is presented in Table 2. In both renovation methods, among the sown grasses the largest percentages had *L. perenne* (average 23.9% DM) and *P. pratense* (average 21.0% DM). It was found that the percentage of *L. perenne* was approximately 18% higher in the case of full cultivation (average 26.3% DM) compared to overdrilling (21.5% DM). The highest percentage for *P. pratense* was determined (average 33.3% DM) after overdrilling with mixture III and with the highest fertilization level of 300 NPK. *Festulolium braunii* had the lowest participation in species composition (average 6.7% DM) and it was independent of the renovation method. The largest percentage of *L. multiflorum* was identified after full cultivation and the highest dose of fertilization (300 NPK) – 25.2% of DM, while the lowest percentage was on plots after overdrilling and without fertilization – 3.3% DM.

The botanical-weight analysis of sward revealed that tall grasses participation was 46.2% of DM, and short grasses 23.9% DM. The percentage of *T. pratense* and *T. repens* in species composition decreased with an increase in the level of nitrogen fertilization, while the percentage of sown grasses increased with an increase of nitrogen fertilization under both methods of renovation. The average participation of sown grasses was 70.1% DM. The sown species participation (grasses and legumes together) totalled 90.0% DM, on average. The percentage of *T. pratense* in the sward was 19.9% DM and *T. repens* – 18.9% DM, herbs and weeds participation was 11.3% DM, on average.

Table 2. Species composition of the sward from first harvest (% DM); the average of values from 2010-2012 are shown

Specification			*F. braunii*	*F. pratensis*	*L. multiflorum*	*L. perenne*	*P. pratense*	Other grasses	*T. pratense*	*T. repens*	Weeds & herbs
Full cultivation	Mix I	0	5.5	12.1	1.9	25.5	–	25.3	–	–	29.7
		140 PK	6.9	16.2	5.6	24.3	–	18.9	–	–	28.1
		220 NPK	8.2	14.9	7.3	29.9	–	22.6	–	–	17.1
		300 NPK	7.3	16.8	8.1	30.1	–	21.2	–	–	16.5
	Mix II	0		12.7	3.8	22.7	14.4	18.1	–	24.2	5.1
		140 PK		10.3	6.1	25.1	15.9	20.9	–	19.7	2
		220 NPK		13.1	7.4	23.7	18.2	15.3	–	13.4	8.9
		300 NPK		14.8	8.4	21.8	16.7	16.9	–	11.6	9.8
	Mix III	0		10.1	3.1	26.1	16.1	11.3	26.6	–	6.7
		140 PK		11.4	4.4	27.9	22.1	8.7	23.3	–	2.2
		220 NPK		10.7	7.6	28.4	23.5	13.1	16.1	–	0.6
		300 NPK		13.1	8.4	30.1	19.9	12.9	10.2	–	5.4
Overdrilling	Mix I	0	4.3	10.5	1.1	15.9	–	30.3	–	–	37.9
		140 PK	5.9	11.4	5.3	18.7	–	24.7	–	–	34
		220 NPK	7.1	12.7	6.2	27.9	–	26.3	–	–	19.8
		300 NPK	8.4	11.9	7	30.4	–	28.9	–	–	13.4
	Mix II	0		10.3	2.8	20.5	22.2	16.9	–	26.9	0.4
		140 PK		14.7	6.6	21.4	22.1	10.2	–	22.8	2.2
		220 NPK		12.9	7.1	22.9	17.6	13.7	–	16.7	9.1
		300 NPK		13.5	5.9	21.4	17.3	12.6	–	15.5	13.8
	Mix III	0		11.9	3.4	15.7	23.1	15.5	28.6	–	1.8
		140 PK		14.6	6.6	17.9	23.1	10.3	24.8	–	2.7
		220 NPK		12.4	6.1	22.3	30.1	9.4	17.9	–	1.8
		300 NPK		15.3	5.9	23.7	33.3	7.8	11.7	–	2.3

The results of ANOVA revealed that all applied treatments (renovation method, forage mixture and mineral fertilization), as well as interactions among treatments, had significant effect on the average annual yield (Table 3).

The use of overdrilling in meadow renovation increased crop yield by 19% as compared to the full cultivation method (full cultivation average 7.206 kg $DM \cdot m^{-2}$, overdrilling 8.927 kg $DM \cdot m^{-2}$), (Table 4). Analysis of the renovation method and type of mixture revealed that the highest yield was obtained after overdrilling, using the mixture of grasses with *T. pratense* (Mix III), (Table 4).

Mixture I gave the lowest annual yield (6.667 kg $DM \cdot m^{-2}$), mixture II medium (8.422 kg $DM \cdot m^{-2}$) while mixture III the highest annual yield (9.110 kg $DM \cdot m^{-2}$), (Table 5).

Analysing the influence of the applied mixtures and mineral fertilization, the highest yield was obtained after sowing forage grass mixtures with *T. pratense* (Mix III) with phosphorus and potassium (140 PK) fertilizer (10.333 kg $DM \cdot m^{-2}$), (Table 5).

Finally, taking into account the interaction of renovation method, the type of mixture and mineral fertilization, the highest yield was determined on plots where overdrilling was used with a mixture of forage grasses with *T. pratense* (Mix III) under 140 PK fertilization (10.558 kg $DM \cdot m^{-2}$), (Table 4). The use of PK fertilization on plots renovated by full cultivation also gave quite good yield with mixture III (10.109 kg $DM \cdot m^{-2}$). It is noticeable that mixture III produced high biomass even without fertilization (10.077 kg $DM \cdot m^{-2}$) when overdrilling was used. The lowest yield was given by mixture I on plots with full cultivation (average 5.381 kg $DM \cdot m^{-2}$), especially on those plots without fertilization (4.083 kg $DM \cdot m^{-2}$).

Table 3. The detailed results of ANOVA for split-split-plot design for average annual yield over the period 2010-20112

	Df	Sum square	Mean square	F	p	Newman-Keuls critical ranges
Renovation method (A)	1	53.344	53.344	1955.421	0.001	n.c
Forage mixture (B)	2	76.201	38.100	1074.999	0.000	0.155
A × B	2	6.582	3.291	92.858	0.000	0.252
Mineral fertilization ©	3	11.764	3.921	24.511	0.000	0.359
A × C	3	5.478	1.826	11.414	0.000	0.518
B × C	6	18.804	3.134	19.589	0.000	0.643
A × B × C	6	4.065	0.677	4.235	0.003	0.894

Table 4. Effect of the renovation method, forage mixture and mineral fertilization on the average annual yield over the period 2010-2012 [kg $DM \cdot m^{-2}$]; all compared groups differ significantly from each other (for values of critical ranges see Table 3)

Fertilization level	Full cultivation			Overdrilling		
	Mix I	Mix II	Mix III	Mix I	Mix II	Mix III
0	4.083	7.083	7.814	6.859	8.949	10.077
140 PK	5.365	7.994	10.109	7.840	9.718	10.558
220 NPK	5.801	8.821	7.994	8.231	8.474	8.603
300 NPK	6.275	7.032	8.096	8.878	9.308	9.628
Average	5.381	7.732	8.503	7.952	9.112	9.716

Table 5. Effect of used forage mixtures and mineral fertilization on the average annual yield over the period 2010-2012 [kg DM·m^{-2}] average for both renovation methods; all compared groups differ significantly from each other (for values of critical ranges see Table 3)

Fertilization level	Mix I	Mix II	Mix III	Average
0	5.471	8.016	8.946	7.478
140 PK	6.603	8.856	10.333	8.597
220 NPK	7.016	8.647	8.298	7.987
300 NPK	7.577	8.170	8.862	8.203
Average	6.667	8.422	9.110	

DISCUSSION

In the selection of species composition of the mixture used for meadow renovation, meteorological conditions of the region should be considered (Goliński, 2008). Based on our experiment, it was found that the weather conditions during emergence and in the subsequent years of the sward usage allowed a proper development of the sown species.

In our study, a higher density of seedlings was obtained as a result of full cultivation rather than by overdrilling. Analysis of the applied forage mixtures revealed that the highest number of seedlings occurred in plots where a mixture of forage grasses was used, while the lowest number was after sowing a mixture of grasses with *T. pratense*. In species composition of the examined sward the largest participation, in the case of both renovation methods, was noted for *L. perenne* and *P. pratense*. Our results have shown that nitrogen fertilization influenced the participation of *T. pratense* and *T. repens* in the sward. An increase in the nitrogen dose has previously been found to decreased the percentage of *Trifolium* species, while increasing the percentage of grasses (Frame, 2005; Black *et al*., 2009; Frankow-Lindberg *et al*., 2009; Sanderson *et al*., 2013; Kulik *et al*., 2015; Tracy *et al*., 2015). The participation of sown species, including legumes, reached 90.0% of DM in our experiment. Similar values for sown species in multi-species mixtures were obtained by Baryła and Kulik (2012). The participation of *T. pratense* and *T. repens*, regardless of the renovation method and nitrogen levels, was about 20% in the species composition during the considered period. Baryła and Kulik (2012) and Kulik *et al*. (2015) found a higher proportion of *T. pratense* in species composition after overdrilling.

The results of our experiment show that the usage of overdrilling in sward renovation increased the crop yield by 19% as compared to full cultivation. Results of other studies (Han *et al*., 2012; Aires *et al*., 2014) also showed a similar increase. Legume-grass mixtures are used to improve the yield of grasslands and forage quality (Graves *et al*., 2012, Sanderson *et al*., 2013). When the interactions of applied forage mixtures and mineral fertilization were assessed in our experiment, the highest yield was obtained in plots where the mixtures of forage grasses with *T. pratense* and phosphorus-potassium fertilizer were used.

The information that grassland renovation on sandy soil is more effective without nitrogen fertilization, but with overdrilling and the usage of legumes in the seed mixture is important for practical management as well as for environmental protection. Despite the poorer initial development of the sward (lower number of seedlings), the advantages of this method seem to be important. On sandy soil periodic renovation is a treatment that is necessary for optimal development of a sward.

CONCLUSIONS

1. Overdrilling as a method of renovation leads to a significantly higher production yield than through full cultivation, although initial development of the sward was better when full cultivation was applied.
2. Addition of legumes, particularly *T. pratense*, to a grass mixture and the application of phosphorus-

-potassium fertilization significantly increased the yield of the grassland.

3. The species with the highest percentage in the sward were *Lolium. perenne* and *Phleum pratense,* therefore, they should be considered as highly valuable for meadow renovation.

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WPŁYW METODY RENOWACJI, ZASTOSOWANEJ MIESZANKI I NAWOŻENIA NA PLON ŁĄKI NA GLEBIE PIASZCZYSTEJ

Streszczenie

Optymalne plonowanie odtwarzanej łąki jest zależne od odpowiednio dobranej metody renowacji oraz dalszego zrównoważonego użytkowania. Celem prezentowanych badań była ocena wpływu metody renowacji, zastosowanej mieszanki i nawożenia mineralnego na rozwój początkowy, skład gatunkowy i plon łąk na glebie piaszczystej. Doświadczenie było prowadzone w Zakładzie Doświadczalnym Swojec, należącym do Uniwersytetu Przyrodniczego we Wrocławiu. Jako czynniki doświadczenia zastosowano dwie metody renowacji runi (siew szczelinowy i pełną uprawę), trzy typy mieszanek pastewnych: złożoną tylko z traw (mieszanka I), trawy z dodatkiem *Trifolium repens* (mieszanka II) i trawy z *T. pratense* (mieszanka III) oraz trzy typy nawożenia mineralnego (0, 140 PK (40 P + 100 K), 220 NPK (80 N + 40 P + 100 K), 300 NPK (160 N + 40 P + 100 K). Największy udział w składzie gatunkowym w latach 2010–2012 miały *Lolium perenne* i *Phleum pratense* przy obydwu metodach renowacji. Trawy wysokie osiągały średnio 47%, trawy niskie 24% i rośliny motylkowe 29% suchej masy. Siew bezpośredni istotnie podnosił plon w porównaniu z zastosowaniem pełnej uprawy, także zastosowanie nawożenia fosforem i potasem (140 PK) przy braku nawożenia azotem wpływa na uzyskanie najwyższego plonu. Jeżeli analizowany jest kompleksowy wpływ zastosowanych czynników, najwyższy plon uzyskano na poletkach, gdzie zastosowano siew szczelinowy mieszanki traw z *T. pratense* (mieszanka III) oraz nawożenie fosforowo-potasowe przy braku nawożenia azotem.

Słowa kluczowe: kiełkowanie, mieszanka pastewna, pełna uprawa, plon, siew szczelinowy, skład gatunkowy