Journal of Elementology ISSN 1644-2296

Kacorzyk P., Głąb T. 2017. *Effect of ten years of mineral and organic fertilization on the herbage production of a mountain meadow*. J. Elem., 22(1): 219-233. DOI: 10.5601/jelem.2016.21.2.1032

ORIGINAL PAPER

EFFECT OF TEN YEARS OF MINERAL AND ORGANIC FERTILIZATION ON THE HERBAGE PRODUCTION OF A MOUNTAIN MEADOW*

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Abstract

The objective of this study was to determine the effect of long term organic fertilization supplemented by mineral fertilizers on the grassland productivity. A ten-year-long experiment was conducted in mountainous conditions, in the south of Poland. Six treatments were evaluated: unfertilized control (UC), mineral P and K fertilization (PK), mineral P, K and N fertilization (NPK), sheep manure fertilizations (SM10 and SM15) and sheep manure supplemented with mineral P and K (SM10PK). The botanical composition, dry matter of the yield and the content of total nitrogen, phosphorus and potassium were determined every year. During the ten years of the experiment, changes in the botanical composition were observed. Fertilization, both mineral and organic one, resulted in the increasing grass participation at a reduced percentage of forbs up to 18% on average for all treatments. Some new grass species, *Holcus mollis, Trisetum flavescens, Dactylis glomerata* and *Phleum pratense*, appeared after ten years of fertilization. The PK and SM10 treatments were characterized by an increased percentage of legumes. The highest herbage production was noticed at the NPK fertilization (4.55 t DM ha^{-1}). Fertilization significantly influenced the N content in plant biomass, with the highest N concentration effected by the PK treatment. Plants with manure fertilization, SM10, SM15 and SM10PK were characterized by similar N concentrations. The mineral fertilization NPK and control UC resulted in lower N uptake. It can be concluded that the highest potential of biomass production was achieved by sheep manure fertilization at the dose of 10 t ha^{-1} supplemented with mineral P and K fertilization (SM10PK).

Keywords: grassland, sheep manure, mineral fertilizers, botanical composition, yield.

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* This research was financed by the Ministry of Science and Higher Education of the Republic of Poland (statutory funds No. DS/3111 and grant no. 6PO605821).

INTRODUCTION

Appropriate and adequate fertilization is a widely known practice leading to increased dry matter production in meadows and has been studied for many years (Wilkinson, Langdale 1974, Aydin, Uzun 2005). In mountainous regions, organic fertilizers are very commonly used because of their availability and for economic reasons. Mineral fertilization is usually recommended for better nutrient balance. It is well documented that not only fertilization levels but also nutrient proportions affect sward biomass production (Chintala et al. 2012). Malhi et al. (2004) studied the effect of N, P and K levels on the productivity of timothy grass. They found that an application of N markedly increased the dry matter yield whereas P and K had only moderate effects. The supply of N and P in the form of fertilizers has been proven to significantly influence the dry matter yield of grasslands. An increase in herbage production as a result of fertilization is connected with higher dry matter production of particular sward components, but changes in the botanical composition of the sward are also observed (Kalmbacher, Martin 1996). The most important nutrient responsible for biomass production is nitrogen. However, the N fertilization used to increase dry matter yield inhibits the diversity and results in changes in the botanical composition of meadow sward (Aydin, Uzun 2005). The relationship between species richness and nutrient supply has been widely investigated (Janssens et al. 1998, McCrea et al. 2001, Wassen et al. 2005, Oelmann et al. 2011). Lee and Lee (2000) stated that fertilization with nitrogen stimulates grass growth, but depresses the growth of legumes. Phosphorus fertilizers also affect the botanical composition. According to Mevlut et al. (2007), large concentrations of P are associated with little floristic diversity but play a favourable role in the occurrence of legumes. Concentrations of potassium appear to increase diversity (Aydin, Uzun 2005). The significant impact of fertilization on biomass production is ascribed not only to nutrient quantities but also to their mutual proportions. Koerselman and Meuleman (1996) suggested that the N:P ratio in plant biomass is a useful tool for identification whether N or P limits plant growth. They reported that a higher N:P ratio indicated P limitation, while a lower one indicated N limitation.

Our objective was to evaluate the long-term effect of organic fertilization supplemented by mineral fertilizers on the grassland productivity. This paper reports changes in the botanical composition, herbage production of mountain meadow and the basic macronutrient content as well as N:P ratios. The aim of this study was to determine optimum doses of organic and mineral fertilizes for productivity of meadows.

MATERIALS AND METHODS

Site, location and climate

This field experiment was located in Czarny Potok near Krynica, Poland (latitude 49°24′ N, longitude 20°55′ E, 650 m a.s.l., slope 4° NE). The climate in the experimental site is temperate-continental with an average annual precipitation of 1090 mm and mean daily temperature of 6.2°C. Data from the meteorological station at the site are collated in Table 1. The field experiment was located on Haplic Cambisol Dystric soil. Table 2 reports the basic soil characteristics at the experimental site.

Table 1

Average monthly temperature and total precipitation at the experimental site during the period 2001-2010

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	1968-2001
Monthly average temperature (°C)											
January	-3.0	-3.9	-62	-7.2	-4.2	-8.2	1.9	-1.7	-4.9	-6.3	-4.3
February	-2.9	0.7	-5.9	-2.9	-6.0	-6.1	-0.8	-0.8	-3.1	-3.3	-2.5
March	1.3	2.4	0.8	0.5	-2.3	-2.3	4.4	1.6	0.0	0.4	1.8
April	5.2	5.5	5.0	6.3	6.0	6.5	7.2	7.1	8.7	6.2	6.0
May	11.9	13.7	13.2	9.0	11.3	10.7	13.6	11.8	10.8	11.1	11.3
June	12.2	15.0	15.8	13.7	13.4	14.3	15.1	16.4	13.5	14.5	13.9
July	16.7	17.3	16.8	15.2	16.7	18.6	17.1	16.9	17.0	17.5	15.4
August	16.4	16.7	16.6	15.3	14.7	15.0	16.6	16.4	15.8	16.3	15.0
September	9.4	9.8	10.9	10.3	12.1	13.1	10.5	10.1	12.6	9.9	11.0
October	9.1	4.6	4.8	7.8	7.2	8.3	5.9	7.6	5.5	3.5	7.3
November	0.9	3.3	2.6	1.3	0.9	3.4	-0.5	3.2	2.9	4.9	1.5
December	8.0	-6.9	-0.3	-2.3	-3.0	-0.5	-2.4	-0.8	-2.5	-6.2	-2.7
Annual mean	7.1	6.5	6.2	5.6	5.6	6.1	7.4	7.3	6.4	5.7	6.1
Sum of monthly precipitation (mm)											
January	70	67	20	63	163	33	109	43	24	22	41
February	56	53	34	142	81	61	55	25	31	26	37
March	46	48	33	73	104	87	73	95	101	40	44
April	120	35	33	64	84	79	26	47	13	83	61
May	69	132	138	113	109	132	60	40	104	195	88
June	207	126	83	125	200	164	94	40	194	204	121
July	318	187	88	285	137	62	55	185	119	156	122
August	109	193	5	100	143	153	58	61	116	119	90
September	147	93	62	30	61	20	212	108	42	199	78
October	32	123	35	56	30	29	58	59	78	18	49
November	75	41	31	110	25	131	105	32	72	31	52
December	83	40	25	22	116	45	28	47	36	40	48
Annual sum	1332	1136	586	1183	1250	997	931	782	928	1132	831

Table 2

Basic physical and chemical soil properties of Haplic Cambisol Dystric from the trial location (0-15 cm layer)

pH (KCl)		4.2
Total organic C	(g kg^{-1})	29.4
Total N	(g kg^{-1})	3.50
P	(mg kg^{-1})	11.0
K	(mg kg^{-1})	75.5
Mg	(mg kg^{-1})	76.0
Bulk density	(g cm^{-3})	1.14
Solid particle density	(g cm^{-3})	2.56
Sand	(g kg^{-1})	600
Silt	(g kg^{-1})	380
Clay	(g kg^{-1})	20
Texture		sandy loam

Field trial design and treatments

The research project was set up on a mountain meadow and lasted from 2001 to 2010. The dominant species in the meadow's botanical composition were *Festuca rubra*, *Festuca pratensis* and *Deschampsia caespitosa.* The experiment was laid out in a randomized block design with three replications and a plot size of 2×6 m (12 m^2). Six fertilization treatments were evaluated:

1) unfertilized control (UC);
2) mineral fertilization (PK) with the P and K doses of 18 kg P ha^{-1} and 50 kg K ha^{-1};
3) mineral fertilization (NPK) 100 kg N ha^{-1}, 18 kg P ha^{-1} and 50 kg K ha^{-1};
4) sheep manure (SM10) with the dose of 10 t ha^{-1} fresh matter (69 kg N ha^{-1}, 14 kg P ha^{-1}, 60 kg K ha^{-1}) applied once a year;
5) sheep manure (SM10PK) of 10 t ha^{-1} fresh matter and mineral fertilization with doses of 4 kg P ha^{-1} and 31 kg K ha^{-1};
6) sheep manure (SM15) with the dose of 15 t ha^{-1} fresh matter (103 kg N ha^{-1}, 21 kg P ha^{-1}, 90 kg K ha^{-1}).

The following forms of fertilizers were applied over the periods indicated below: phosphorus in the form of tri-superphosphate was applied once a year in April; potassium in the form of 56% potash salt was divided into two equal portions and applied for the first and the second regrowth; nitrogen in the form of ammonium nitrate was applied twice a year in the proportions of 60% and 40% of the total dose, for the first and the second regrowth. The supplementary dose of nitrogen applied to the plot nourished with manure was given in one dose for the first regrowth. Sheep manure was applied every year, in April. Two harvests were carried out at the end June and August every year.

Measurements

The botanical composition was determined every year just before the first cut using the Klapp method. The dry matter of the yield was determined by harvesting plants from the whole surface of the plots and drying a 500 g subsample at 70°C to constant weight. The content of total nitrogen was determined with the Kjeldahl method after sample mineralization in concentrated sulphuric acid. Phosphorus and potassium concentrations were assessed by using inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Statistics

Analysis of variance for a randomized block design was performed in order to evaluate the significance of different organic and mineral fertilizations on plant yields and nutrient content, using the statistical package Statistica 9.0 (StatSoft Inc., Tulsa, OK, USA). Means were compared according to the Tukey's test at the level of significance of $P < 0.05$.

RESULTS

Botanical composition

The most frequent species at the trial location in 2001 were *Festuca rubra*, *Agrostis capilaris* and *Deschampsia caespitosa* from the *Poaceae* family (Table 3). The only species from the *Fabaceae* family was *Trifolium repens*. During the ten years of the experiment, changes in the botanical composition were observed. Fertilization, both mineral and organic one, resulted in an increased grass share. Some new grass species appeared after ten years of fertilization: *Holcus mollis, Trisetum flavescens, Dactylis glomerata* and *Phleum pratense.* The percentage of grasses was 66% at the control UC as an average for the ten years of the trial (Figure 1). At the treatment with mineral P and K fertilization, percentages of grasses were similar. However, the NPK fertilization and all organic fertilization treatments increased the percentage of grasses. The highest value was noticed for the NPK object (82%), and for the SM10, SM15 and SM10PK it was 71, 74 and 76%, respectively.

The fertilization applied significantly affected the percentage of legumes. The PK treatment was characterized by an increase in the number of legumes. The participation of *Trifolium repens* in 2010 was at the same level as in 2001 but a new species appeared, namely *Trifolium pratense.* The PK fertilization also increased the percentage of legumes. The participation of legumes at the UC, the unfertilized control, was 6% on average during the period of 2001-2010, whereas at the PK it increased up to 20%. The SM10 was also characterized by an increasing legume participation (9%). Any other fertilization variant tested reduced the number of legumes.

The participation of forbs at the UC did not change during the whole

Table 3

The occurrence (%) of species at the beginning of the experiment (2001) and after ten years (2010) of different fertilization treatments

Species	2001	2010					
		UC	PK	NPK	SM10	SM10PK	SM15
Cynosurus cristatus L.	3	+	7	+	+	3	5
Holcus mollis L.			+	15	5		
Trisetum flavescens L.		+	10	+	2	1	1
Festuca rubra L.	27	19	15	10	15	27	25
Festuca pratensis Huds.	8	7	4	20	16	10	9
Dactylis glomerata L.				4	10	1	2
Agrostis capillaris L.	11	25	20	5	17	39	27
Agropyron repens L.	+		+	8	+	+	+
Deschampsia caespitosa L.	11	5	3	7	3	2	2
Anthoxanthum odoratum L.	2	1	1	+	+	+	+
Phleum pratense L.		+	7	5	6	1	5
Poa pratensis L.	3	2	5	12	7	3	2
Poa annua L.	+						
Poa trivialis L.	3		3	2	4	2	7
Trifolium repens L.	6	4	6	+	1	+	2
Trifolium pratense L.		1	4		+	3	+
Plantago lanceolata L.	4	3	+		+	+	1
Leontodon hispidus L.		1					
Hypericum perforatum L.		1	+	+	+		
Campanula patula L.	+	2	1	+		1	
Prunella vulgaris L.		1					
Stellaria graminea L.		+	+	+	+		
Ranunculus acris L.	1		2	+	+	+	
Ranunculus repens L.	4	2	1	1	2		+
Achillea millefolium L.	1	+	1		+	+	+
Taraxacum officinale F. H. Wigg.	5	1	+	+	+	+	+
Cirsium rivulare Jacq.	1	5		3	2	1	
Veronica chamaedrys L.		3	1	+	1	+	2
Veronica persica Poir.	1						
Galium boreale L.		1					
Alchemilla pastoralis Bus.	6	9	2	4	4	3	3
Cerastium holosteoides Fr. em. Hyl.			+				
Rumex acetosa L.	2	6	5	2	3	2	5

+ species in participation lower than 1%

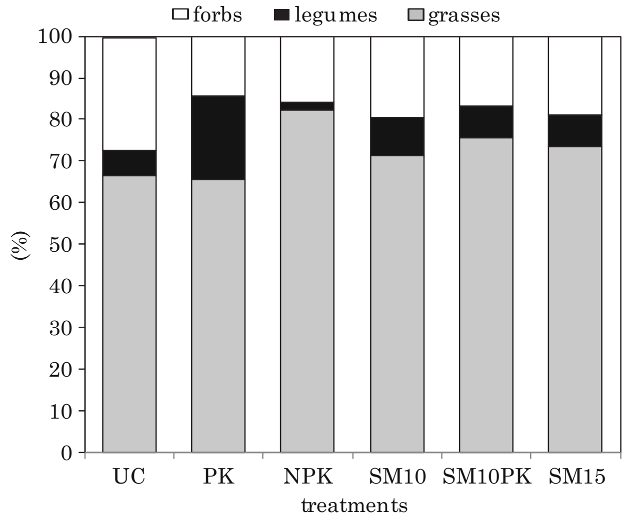

Fig. 1. Effect of different mineral and organic fertilization on percentage of grasses, legumes and forbs. Results are the averages of ten years, 2001-2010

experimental period and it was approximately 27%. The most frequent species were *Ranunculus repens, Taraxacum officinale, Cirsium rivulare, Alchemilla pastoralis* and *Rumex acetosa*. However, significant impact of fertilization on this group of species was observed. All fertilization treatments, mineral or organic ones, reduced the percentage of forbs up to 18% on average for all the treatments. It was observed that forb species were replaced by grasses in the treatments with organic fertilization, SM10, SM15 and SM10PK. When the PK fertilization was applied, forbs were replaced by legumes.

The correlation coefficients for the relationship between the total amount of macronutrients N, P and K, applied as mineral or organic amendments, and the percentage of grasses, legumes and forbs are presented in Table 4. Grasses were positively correlated with the amount of all macronutrients N, P and K. However, legumes were correlated only with the N fertilization level. Percentages of forbs were related to the P and K doses. Detailed regression models for significant correlations are presented in Figure 2.

Table 4

Correlation coefficients for the relationship between amounts of N, P and K applied with the mineral and organic fertilizers and percentages of grasses, legumes and forbs in the sward. Correlation coefficients significant for $P < 0.05$

Plants	N	P	K
Grasses	0.581	0.332	0.271
Legumes	-0.483	ns	ns
Forbs	ns	-0.489	-0.339

ns – non-significant

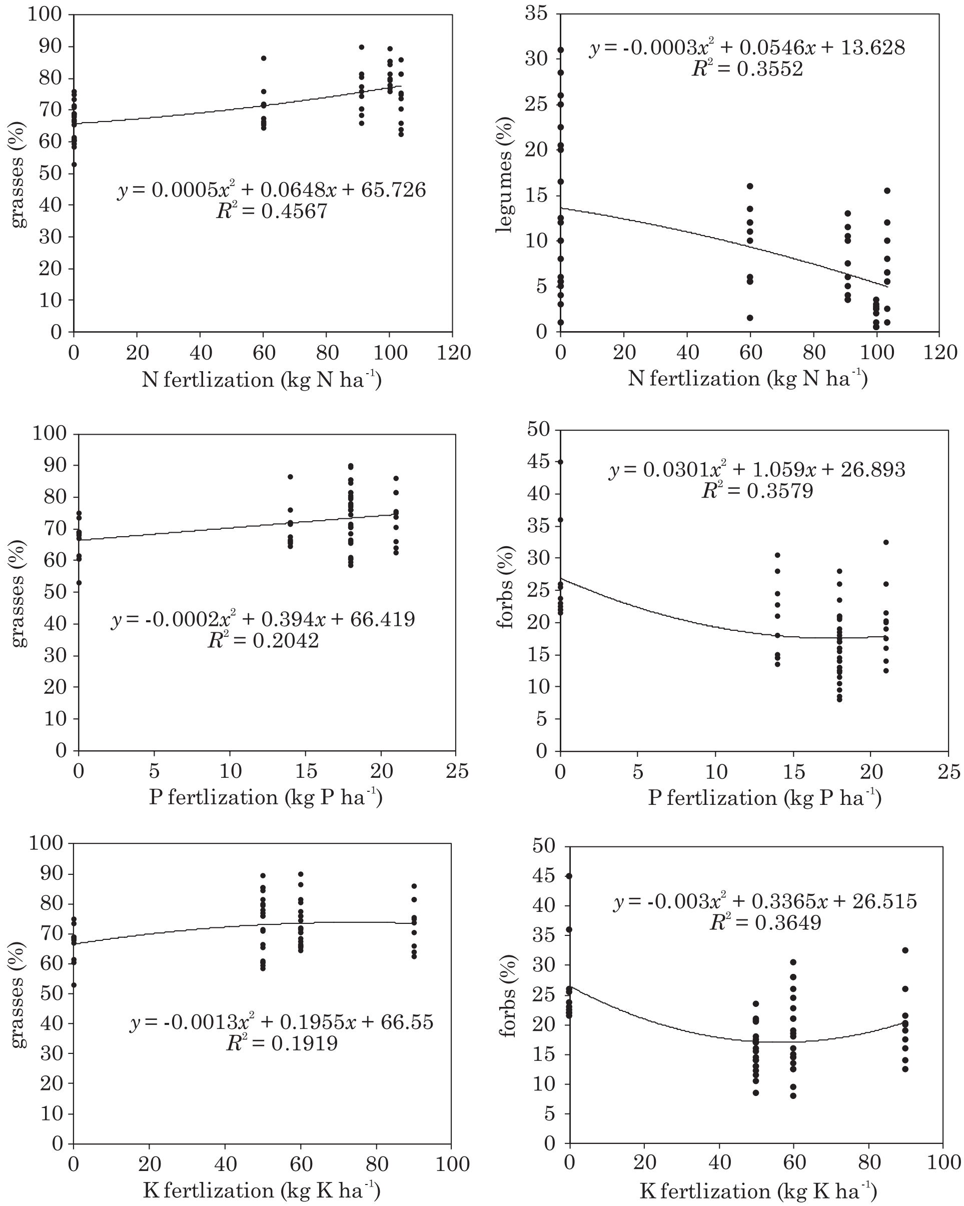

Fig. 2. Effect of N, P and K fertilization doses on the percentages of grasses, legumes and forbs in the sward. Data collected during the ten-year experiment, 2001-2010

The species richness in the tested meadow was of 17.5 on average (Figure 3). It consisted of three main species groups, grasses, legumes and forbs, with the species richness of 8.4, 1.6 and 7.5, respectively. The species richness was not affected by any fertilization treatment applied.

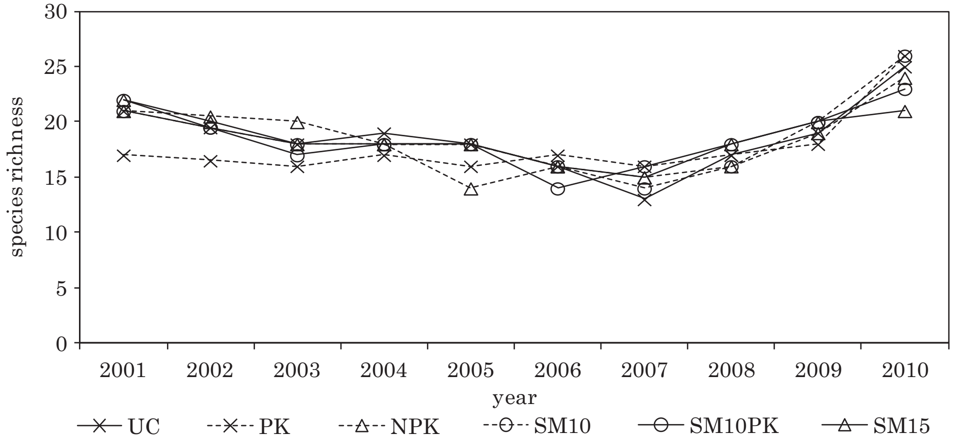

Fig. 3. Effect of different mineral and organic fertilization on species richness. Results are the averages of ten years, 2001-2010

Herbage production

During the ten-year observations, a relationship between the weather and yields was noticed. In 2003, 2006, 2007 and 2008, the herbage production was lower than in the other years as a consequence of lower annual precipitation and higher temperatures recorded (Figure 4). The tested mountain meadow

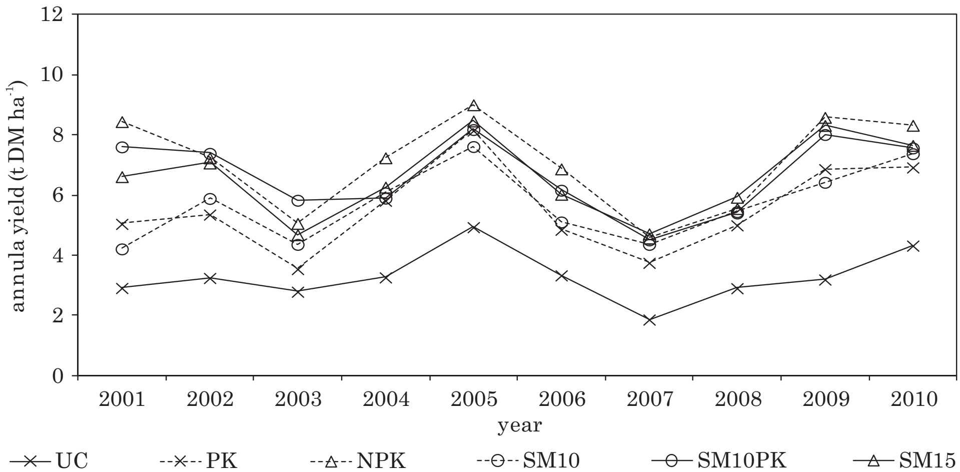

Fig. 4. Effect of different mineral and organic fertilization on annual yields of meadow in mountainous conditions. Results are the averages of ten years, 2001-2010

was the two-cut maintenance type with the first cut harvested higher by 67% than the second one (Table 5). The fertilization system used in the experiment affected the herbage production. However, the differences were more significant during the first cut than during the second one. The highest herbage production was noticed at the NPK (4.55 t DM ha^{-1} in average of 2001-2010). The dry

Table 5

Herbage production, the N, P and K content and the N:P ratio in plants. Results are the averages of ten years, 2001-2010

Treatments	Yield (t DM ha^{-1})	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	N:P
1st cut					
UC	1.91	18.91	1.76	14.77	11.11
PK	3.38	20.43	2.26	17.06	9.41
NPK	4.55	18.87	2.00	17.23	9.82
SM10	3.55	19.78	2.09	20.74	9.88
SM10PK	4.26	19.38	2.22	18.84	8.98
SM15	4.07	19.20	2.43	22.91	8.24
2nd cut					
UC	1.33	21.89	1.80	13.61	12.69
PK	2.02	25.16	2.48	15.91	10.46
NPK	2.55	22.06	1.94	16.36	12.36
SM10	2.15	23.95	2.36	18.68	10.26
SM10PK	2.41	22.66	2.48	18.65	9.30
SM15	2.52	23.32	2.50	21.19	9.67
Means for cuts					
1st cut	3.62	19.43	2.13	18.59	9.57
2nd cut	2.16	23.17	2.26	17.40	10.79
Means for treatments					
UC	1.62	20.40	1.78	14.19	11.90
PK	2.70	22.80	2.37	16.49	9.94
NPK	3.55	20.46	1.97	16.80	11.09
SM10	2.85	21.86	2.23	19.71	10.07
SM10PK	3.33	21.02	2.35	18.75	9.14
SM15	3.29	21.26	2.47	22.05	8.95
LSD (0.05):					
cuts	0.16	0.537	0.093	ns	0.49
treatment	0.27	0.931	0.161	2.15	0.85
cut x treatment	0.38	ns	ns	ns	ns

ns – non-significant

matter production at the SM10PK and SM15 was comparable: 4.26 and 4.07 t DM ha^{-1}, respectively. Much lower yields were achieved from the PK and SM10 treatments. The lowest herbage production was observed at the control UC object (1.91 t DM ha^{-1}). During the second harvest, differences between the treatments were noticeable only between the UC (1.33 t DM ha^{-1}) and the other fertilized treatments (2.33 t DM ha^{-1} on average). The correlation between the total amount of macronutrients, N, P and K, applied as mineral or organic amendments and the annual yields was statistically significant, with the correlation coefficients equal 0.608, 0.619 and 0.543, respectively. The regression models for this relationship are presented in Figure 5.

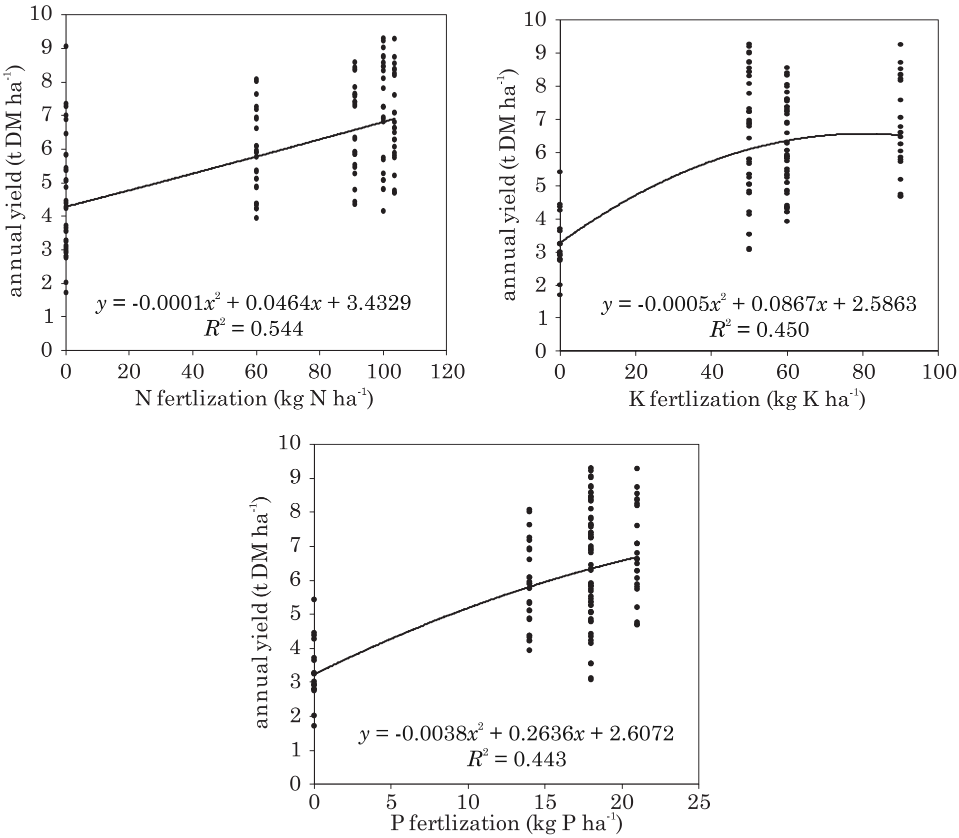

Fig. 5. Effect of N, P and K fertilization doses on annual dry matter production. Data collected during the ten-year experiment, 2001-2010

Plant N, P and K content

The nitrogen content in plants was of 21.3 g kg^{-1} on average during the ten years of the experiment (Table 5). A significantly higher N content was determined in the second cut (23.17 g kg^{-1}) than in the first one (19.43 g kg^{-1}). Fertilization significantly influenced the N content in plant biomass. The highest N concentration was noticed at the PK treatment (22.80 g kg^{-1}). Plants supplied with manure fertilization, SM10, SM15 and SM10PK were characterized by similar N concentrations. The mineral fertilization NPK and control UC resulted in lower N uptake (20.43 g kg^{-1} on average).

Phosphorus content in plants differed in particular cuttings. During the first cut, the average P concentration in plants was 2.13 g kg^{-1}, and it increased in the second harvest to 2.26 g kg^{-1}. The fertilization applied raised the P content in plants compared with the control UC (1.78 g kg^{-1}). The highest P concentration was noticed in the SM15 treatment (2.47 g kg^{-1}).

Potassium content in plants did not depend on the cutting term. It was affected only by a fertilization treatment. Similarly to the N and P content, the lowest potassium concentration was determined in the control, unfertilized object (14.19 g kg^{-1}). The highest K concentration was observed at the SM15 treatment.

The proportion between N and P content in plants was lower in the biomass harvested during the first cut (5.57) than during the second one (10.79). The plants exposed to different fertilization treatments were characterized by different N:P ratios. The N:P ratio above 11 was obtained for the UC and NPK fertilization treatments. Significantly lower values were detected for the PK, SM10 and SM10PK treatments. The lowest N:P ratio was noticed in the SM15 object.

DISCUSSION

Many authors have reported that increased N supply fosters grasses (Hogh-Jensen, Schjoerring 2010). The results obtained with respect to the botanical composition of a meadow confirm that nitrogen fertilization plays a favourable role in the growing conditions of tall grasses like *Festuca pratensis*, *Poa pratensis*, *Dactylis glomerata* and *Agropyron repens* (Leps 1999, Głąb, Kacorzyk 2011). Nitrogen fertilization increased the grass species participation in the tested mountain meadow. The most frequent grass species in the meadow in 2001 was *Festuca rubra* (27%). A significant decrease in the percentage of *Festuca rubra* under high nitrogen supply was confirmed by Mastalerczuk and Stypiński (2005). Similar results were also obtained by other authors in an experiment with different four-year-long fertilization management (Głąb, Kacorzyk 2011).

One of the most important components in the botanical composition of grassland consists of legumes. However, the N fertilization used to increase dry matter yield usually decreases legume ratios in the botanical composition (Aydin, Uzun 2005). It was also recorded that the fertilization with P and K but without N played a favourable role in the competition between legumes and other species (Mevlut et al. 2007, Liebisch et al. 2013). At the beginning of our experiment, legumes were represented only by *Trifolium repens*. As was expected, this species slowly disappeared when mineral fertilization was applied. However, when only P and K fertilization was applied or under organic fertilization regimes, the participation of legumes increased owing to the appearance of *Trifolium pratense* as a new legume species. In the present study, the correlation analysis indicated that legumes negatively responded to N fertilization and did not show response to P or K nutrients. This confirms the thesis that a decrease in the share of legume in meadow biomass due to N application is usually caused by higher utilization of N fertilizers by grass plants and their stronger competitive ability compared to legume plants.

Legumes are characterized by high P demand because of the energy costs associated with N_2 fixation, which is supplied by the synthesis of ATP (Aerts, Chapin 2000, Oelmann et al. 2011). According to Aydin and Uzun (2005), the effect of P fertilizer on a legume proportion in a meadow mixture may only be expected at low doses of N fertilizer. Both the UC and SM10 treatments resulted in an increased legume participation in the sward. The N dose in the SM10 was of 69 kg N ha^{-1}. However, any higher N doses in organic or mineral fertilization treatments resulted in decreasing the proportion of legumes. It could be expected that fertilization, especially N doses, should affect the species richness (Kirkham et al. 2008). Deleterious effects of mineral fertilizers on species diversity were reported by McCrea et al. (2004). Nitrogen is associated with the vigorous growth of tall grasses and a rapid decline of diversity. Marrs (1993) reported that additions of N to formerly species-rich grassland diminished diversity. However, high phosphorus concentrations are associated with poor floristic diversity. Intermediate concentrations of potassium appear to increase diversity. A survey of old European permanent grasslands showed that fairly large concentrations of potassium are compatible with diversity (Janssens et al. 1998). However, our results do not confirm this thesis. None of the fertilization treatments applied affected species richness.

Fertilization and changes in the botanical composition are reflected by herbage production. As it was expected, the first cut was significantly higher than the second one. This effect is usually ascribed to weather conditions, soil moisture and dynamics of humic substance mineralization (Verlinder et al. 2009). Differences between the treatments were more significant during the first cut than during the second one. The increase in biomass yield observed can be ascribed to amounts of N, P and K nutrients incorporated to the soil with the tested fertilizers. However, the greater emphasis should be laid on nitrogen nutrition. This is in agreement with Malhi et al. (2004), who studied the effect of N, P, and K levels on the productivity of timothy grass. They found that an application of N markedly increased dry matter yield, but P and K had only moderate effects.

In general, fertilization, particularly mineral NPK, increased the N, P and K content in biomass. Similar results were also obtained by Liebisch et al. (2013), who observed that fertilization with P, N or K increased concentrations of particular nutrient in aerial plant biomass. The mean P concentration of 2.2 g kg^{-1} in herbage biomass determined in our research is comparable to the results obtained by Liebisch et al. (2013).

In grasslands, measured P concentrations are interpreted using either critical P concentrations below which dry matter production is limited or as an interaction of P with other elements, like N:P (Venterink et al. 2003). Koerselman and Meuleman (1996) suggested that the N:P ratio in plant biomass is a useful tool to identify whether N or P limits plant growth. It could be expected that soil at a location with low pH value (Table 2) should result in a deleterious effect on the P uptake. However, the results did not confirm this concern. In the present investigation, the N:P ratio was of 10.2 on average. This value was similar to the one obtained by Bailey et al. (1997), who reported the N:P ratio of 9.0 for ryegrass, but was lower than the critical ratios of 14.5 reported by Venterink et al. (2003) and of 14 and 16 reported by Koerselman and Meuleman (1996) for mixed species samples of grasslands managed at low intensity.

In this investigation, plants in the control untreated meadow were characterized by the highest N:P ratio but at the lowest N and P content. The high N:P ratio was also noticed at the NPK treatment. The organic fertilization and the mineral fertilization without nitrogen variants resulted in significantly lower N:P ratios. These results can indicate that yields in the above fertilization treatments are limited by lower nitrogen proportions. In conclusion, higher biomass production potential is achieved by sheep manure fertilization at the dose of 10 t ha^{-1} supplemented with mineral P and K fertilization. The mean herbage production of the SM10PK is as high as the one obtained with the mineral NKP. Furthermore, the botanical composition is more beneficial because of a higher share of legumes.

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