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DIVERSIFIED FERTILIZATION AND ITS EFFECT ON YIELDS AND THE CONTENT OF MINERAL NITROGEN FORMS IN SOIL AND GROUND WATER

Summary

Studies were carried out in a field experiment in the years 2009-2012 on a permanent productive meadow situated on peat-muck soil of the Biebrza Experimental Farm. The aim was to identify the effect of various types and intensities of fertilisation (with cattle manure and liquid manure) on botanical composition of the sward and the content of mineral nitrogen forms in soil. Mineral nitrogen was applied in three doses (N/I – 60, N/II - 90 and N/III – 120 kg N·ha^{-1}). The lowest N dose was accompanied by fertilization with phosphorus and potassium at a rate of 30 and 60 kg ha^{-1}, respectively. Nitrogen fertilisations II and III were supplemented with P (45 and 60 kg P ha^{-1}, respectively) and with K (90 and 120 kg ha^{-1}, respectively). Fertilization with cattle manure and liquid manure was also applied in amounts corresponding to those used with mineral fertilisation. Obtained results showed progressing floristic changes resulting from different forms of fertilisers and increased moisture, which affected yield forming potential in a range from 6 to 9 t dry mass ha^{-1}. Nitrogen fertilisation (with liquid manure or mineral N) at a rate of 90 kg N ha^{-1} resulted in the increase in N-NO_3 in soil layer below 20 cm depth in 2012. In the variant fertilised with 120 kg N ha^{-1}, irrespective of its form, a distinct increase in nitrate content was noted in all soil layers below 20 cm depth, which indicated the leaching of nutrient. Concentrations of mineral forms of N (N-NO_3 and N-NH_4) in ground water tended to increase in plots fertilised with mineral nitrogen irrespective of its does.

***Key words**: peat-muck soil, nitrogen management, permanent meadow*

ZRÓŻNICOWANE NAWOŻENIE I JEGO WPŁYW NA PLONY ORAZ ZAWARTOŚCI W GLEBIE I WODZIE GRUNTOWEJ MINERALNYCH FORM AZOTU

Streszczenie

Badania prowadzono na doświadczeniu łanowym w latach 2009-2012 w ZD Biebrza na wieloletniej łące produkcyjnej na glebie torfowo-murszowej. Celem badań było rozpoznanie wpływu różnych rodzajów i poziomów nawożenia (w tym obornika i gnojowicy bydlęcej) na skład botaniczny runi, plonowanie łąki oraz zawartości mineralnych form azotu w glebie Nawożono azotem w trzech różnych dawkach (N/I – 60, N/II - 90 i N/III – 120 kg N·ha^{-1}), przy czym w najmniejszej dawce stosowano nawożenie fosforem (w ilości 30 kg P·ha^{-1}), a potasem (60 kg K·ha^{-1}) w podanych dawkach, a wraz ze wzrostem azotu odpowiednio nawożono fosforem w ilości od 45 i 60 kg P·ha^{-1}, a potasem – 90 i 120 kg K·ha^{-1}. Stosowano także nawożenie obornikiem i gnojowicą w ilości odpowiadającej nawożeniu mineralnemu. Uzyskane wyniki wskazywały na postępujące zmiany florystyczne, wynikające z formy stosowanego nawożenia oraz wzrostu uwilgotnienia, kształtujące potencjał plonotwórczy stosowanego nawożenia – od ok. 6 do 9 t s.m.·ha^{-1}. Na skutek wzrostu nawożenia do 90 kg N·ha^{-1} notowano wzrost zawartości N-NO3 w 2012 r. w warstwach gleby poniżej 20 cm na skutek nawożenia gnojowica oraz formą mineralną. Na poziomie 120 kg·ha^{-1} niezależnie od formy, stwierdzono wyraźny wzrost zawartości azotu (N-NO_3) we wszystkich warstwach gleby poniżej 20 cm, co świadczy o jego wymywaniu. Z przeprowadzonej oceny stężeń mineralnych form azotu (N-NO_3 i N-NH_4) w wodzie gruntowej wynika tendencja ich wzrostu na obiektach nawożonych nawozami mineralnymi niezależnie od poziomu nawożenia.

***Słowa kluczowe**: gleba torfowo-murszowa, gospodarka azotem, łąka trwała*

1. Introduction and the aim of study

Together with increasing cattle stock, an increased interest is observed in fertilisation of permanent grasslands (including those on peat-muck soils) with natural fertilisers sometimes exceeding the demands. Many authors [e.g. 4, 7, 8, 12, 24] indicate some good points of these fertilisers like the improvement of botanical composition of the sward and yield-forming effects [1, 3].

Fertilisation with natural fertilisers, especially with manure, of meadows on peat-muck soils, which are usually deficient in phosphorus and potassium [13], may supplement these deficits and increase yields [2, 5, 9, 10, 13]. Both mineral and organic fertilisers when deliver significant amounts of nitrogen not used by plants [19, 22] may increase the content of their mineral forms not only in the upper soil layers but also in deeper ones due to leaching [16, 17]. Processes of uncontrolled mineralization of nitrogen as an effect of drying of organic soils are dangerous since they may release large amounts of N-NO_3 [21, 22, 23], which are later washed out of the root zone and penetrate to ground waters [6].

The aim of the study was to recognise the effect of various forms and doses of fertilisation (particularly organic fertilisation) on botanical composition of the sward, meadow yielding and the content of mineral forms of nitrogen in particular layers of peat-muck soil profile.

2. Material and methods

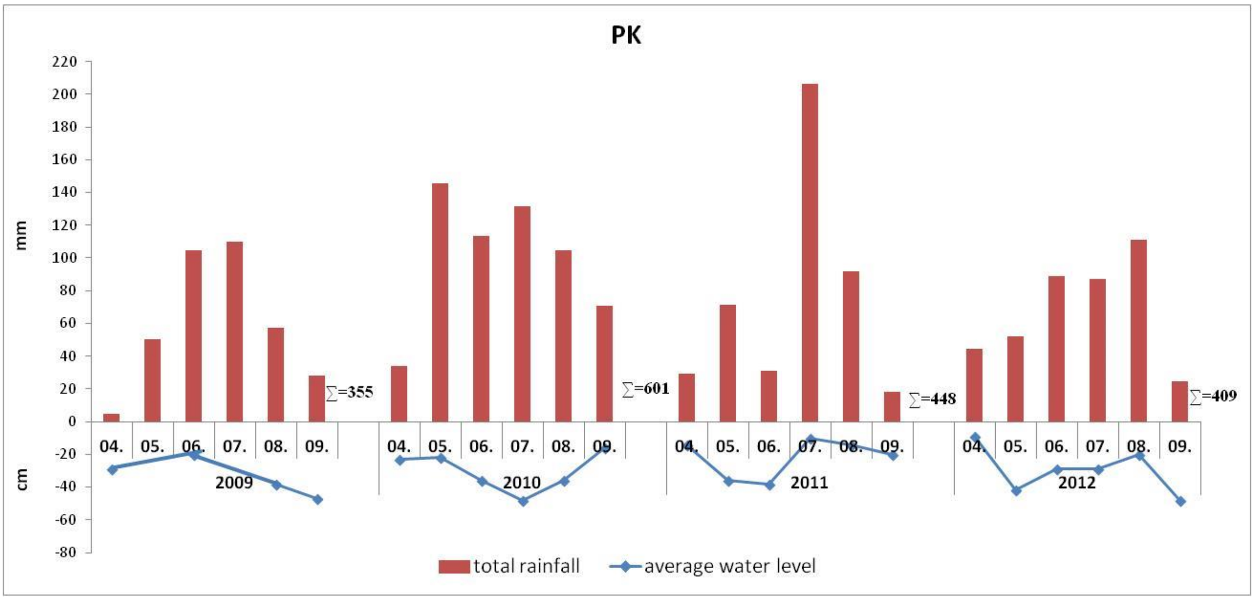
Studies were realised in the years 2009–2012 at the Biebrza Experimental Farm, ITP in field experiment performed on permanent meadow growing on peat-muck soil. The effects of fertilisation with mineral NPK fertilisers, cattle manure and liquid manure were compared. Applied fertilisation variants included: NPK/I – 60 kg N, 30 kg P and 60 kg K·ha^{-1}; NPK/II – 90 kg N, 45 kg P and 90 kg K·ha^{-1}; NPK/III – 120 kg N, 60 kg P and 120 kg K·ha^{-1}. Variants with manure included: O/I – 15–20 t manure·ha^{-1}; O/II – 22.5–30.0 t manure·ha^{-1} and O/III – 32.0-40.0 t manure·ha^{-1} (nutrients introduced in amounts comparable with NPK/I, NPK/II, NPK/III, respectively). Liquid manure was applied in doses: G/I – 25–35 m^3·ha^{-1}; G/II – 37.5–52.5 m^3·ha^{-1} and G/III – 54.0-60.0 m^3·ha^{-1} (amounts of nutrients as above). Mineral fertilisation was applied in a form of ammonium saltpetre, 1/3 of annual dose under each cut, phosphorite powder in spring and potassium sulphate in three equal doses in spring and after the first and second cut. Manure was applied once in autumn with the use of manure spreader. Liquid manure was applied with a splasher in three equal doses in spring and after the first and second cut. Doses of manure and liquid manure were determined based on their nitrogen content assuming the equivalent of N utilisation as 0.5 in manure and 0.7 in liquid manure. The equivalent of P utilisation in both fertilisers was 1 and that of potassium was 0.7 in manure and 0.8 in liquid manure. Phosphorus deficits in liquid manure were supplemented with phosphorite powder.

Plots of an area of 0.3 ha were selected on meadow with five subplots of an area of 25 m^2 displaced in fixed sites of each plot to assess yields and to collect samples of plants, soil and ground water. Wells for measuring ground water table were installed on each plot. Meadow was mown three times and samples of sward were mineralized in sulphuric acid and hydrogen peroxide. Analyses were performed with the use of through-flow analyser. Botanical composition was assessed with the Klapp's method [11]. Dry mass yields and the contents of nitrogen in meadow sward were statistically processed with the Statistica software to calculate least significant differences at $\alpha = 0.05$. The content of inorganic forms of nitrogen (N-NO_3 and N-NH_4) in particular soil layers down to the depth of 110 cm was analysed colorimetrically [19] and results were expressed in mg N dm^{-3} or in kg ha^{-1} in 10 cm soil layer [15]. Water for analyses was taken four times a year: in spring and after each cut and concentrations of inorganic forms of nitrogen were analysed spectrophotometrically with through-flow automatic analyser.

Comparison of vegetation seasons showed significant differentiation of the total sums and distribution of precipitation in particular months. In the beginning of the study (year 2009) the distribution of precipitation was favourable at the lowest sum of rainfall. In the years 2010 and 2011 sums of precipitation were much higher and their distribution was unfavourable, which markedly affected the ground water level. Despite clearly lower sum of precipitations in the vegetation season of 2012, their unfavourable distribution from June till August resulted (as in 2011) in the increase of ground water table and soil moisture.

3. Results

In the experimental variant N/I, the share of grasses in sward markedly decreased from 70% in 2009 to about 50% in 2011 and 2012 (tab. 1). Dominating (more than 5% share in meadow sward) grass species were: the cocksfoot (*Dactylis glomerata* L.), common meadow grass (*Poa pratensis* L.), rough meadow grass (*Poa trivialis* L.), oat grass (*Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Pres) and red fescue (*Festuca rubra* L. s. s.). Remarkable increase in the share of grasses was, however, observed in both variants with organic fertilisation. Legumes in all variants and study years showed small variability and their share in meadow sward did not exceed 5%. The share of weeds significantly increased from 21-25% in 2009 to over 40% in 2012 due to periodical increase of ground water table and soil moisture and the dominant weed species in such conditions were: the creeping buttercup (*Ranunculus repens* L.), dandelion (*Taraxacum officinale* F.H. Wigg.).



Source: own work / Źródło: opracowanie własne

Fig. 1. Distribution of atmospheric precipitation and changes in ground water levels in experimental plots in particular months of compared vegetation seasons

Rys. 1. Rozkład opadów atmosferycznych oraz przebieg poziomów wody gruntowej na doświadczeniu w poszczególnych miesiącach porównywanych sezonów wegetacyjnych

In experimental variant N/II the share of grasses markedly decreased, especially in the years 2011 and 2012. In variant G/II there were less dominating species than in variant G/I. The share of legumes varied from 1 to 5% in particular variants. Similarly to the lower fertilisation variants, an increase in weeding up to 40% was observed here in the years 2011 and 2012 as an effect of dynamic development of two plant populations of the creeping buttercup (*Ranunculus repens* L.) and dandelion (*Taraxacum officinale* F.H. Wigg.).

Table 1. Species composition of plants in particular experimental variants in the years 2009-2012 [in %]
Tab. 1. Skład gatunkowy na poszczególnych obiektach w latach 2009-2012 [%]

Dose N (kg/ha)	Object	Year	Group of plants				
			Grass	Dominant grass species over 5%	Legumes	Herbs and weeds	Dominant weed species over 5%
N/I	O	2009	71	*Dactylis glomerata* L. – 14% *Poa pratensis* L. - 20% *Phleum pretense* L. – 6% *Poa trivialis* L. – 11% *Alopecurus pratensis* L. - 8%	4	25	*Ranunculus repens* L. – 8% *Taraxacum officinale* F.H. Wigg. – 7%
		2010	66	*Dactylis glomerata* L. – 8% *Poa pratensis* L. - 16% *Poa trivialis* L. – 10% *Alopecurus pratensis* L. - 11%	3	31	*Ranunculus repens* L. – 7% *Taraxacum officinale* F.H. Wigg. – 8%
		2011	57	*Poa pratensis* L. - 12% *Poa trivialis* L. – 14% *Alopecurus pratensis* L. - 14%	5	40	*Ranunculus repens* L. – 16 % *Taraxacum officinale* F.H. Wigg. – 8%
		2012	52	*Poa pratensis* L. - 10% *Poa trivialis* L. – 16% *Alopecurus pratensis* L. - 13%	5	43	*Ranunculus repens* L. – 21% *Taraxacum officinale* F.H. Wigg. – 12%
	G	2009	76	*Festuca rubra* L. s. s. – 14% *Dactylis glomerata* L. – 12% *Poa pratensis* L. - 18% *Phleum pretense* L. – 7% *Poa trivialis* L. – 6% *Alopecurus pratensis* L. - 8%	3	21	*Ranunculus repens* L. – 6% *Taraxacum officinale* F.H. Wigg. – 8%
		2010	77	*Festuca rubra* L. s. s. – 10% *Dactylis glomerata* L. – 6% *Poa pratensis* L. - 16% *Phleum pretense* L. – 8% *Poa trivialis* L. – 12% *Alopecurus pratensis* L. - 12%	2	28	*Ranunculus repens* L. – 8% *Taraxacum officinale* F.H. Wigg. – 7%
		2011	59	*Dactylis glomerata* L. – 6% *Poa pratensis* L. - 12% *Phleum pretense* L. – 6% *Poa trivialis* L. – 14% *Alopecurus pratensis* L. - 14%	5	39	*Ranunculus repens* L. – 20% *Taraxacum officinale* F.H. Wigg. – 6%
		2012	54	*Dactylis glomerata* L. – 14% *Poa pratensis* L. - 20% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 11%	4	42	*Ranunculus repens* L. – 24% *Taraxacum officinale* F.H. Wigg. – 10%
	NPK	2009	70	*Dactylis glomerata* L. – 14% *Poa pratensis* L. - 20% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 11%	3	27	*Ranunculus repens* L. – 7% *Taraxacum officinale* F.H. Wigg. – 10%
		2010	76	*Dactylis glomerata* L. – 11% *Poa pratensis* L. - 19% *Poa trivialis* L. – 12% *Alopecurus pratensis* L. - 12%	4	27	*Ranunculus repens* L. – 8% *Taraxacum officinale* F.H. Wigg. – 7%
		2011	58	*Poa pratensis* L. - 17% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 8%	5	33	*Ranunculus repens* L. – 16% *Taraxacum officinale* F.H. Wigg. – 6%
		2012	53	*Poa pratensis* L. - 17% *Poa trivialis* L. – 10% *Alopecurus pratensis* L. - 9%	3	46	*Ranunculus repens* L. – 21% *Taraxacum officinale* F.H. Wigg. – 8%
N/II	O	2009	74	*Festuca rubra* L. s. s. – 8% *Dactylis glomerata* L. - 6% *Elymus repens* L. – 10% *Phleum pratense* L. – 6% *Poa pratensis* L. - 21% *Alopecurus pratensis* L. - 19%	1	25	*Taraxacum officinale* F.H. Wigg. – 9%

		2010	68	*Festuca rubra* L. s. s. – 6% *Elymus repens* L. – 7% *Poa pratensis* L. - 18% *Alopecurus pratensis* L. - 20%	3	28	*Taraxacum officinale* F.H. Wigg. – 7%
		2011	63	*Poa pratensis* L. - 13% *Poa trivialis* L. – 7% *Alopecurus pratensis* L. - 25%	3	40	*Ranunculus repens* L. – 20% *Taraxacum officinale* F.H. Wigg. – 6%
		2012	55	*Poa pratensis* L. - 8% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 25%	3	42	*Ranunculus repens* L. – 25% *Taraxacum officinale* F.H. Wigg. – 9%
	G	2009	70	*Phleum pratense* L. – 8% *Poa pratensis* L. - 20% *Poa trivialis* L. – 6% *Alopecurus pratensis* L. - 16%	5	25	*Ranunculus repens* L. – 8% *Taraxacum officinale* F.H. Wigg. – 9% *Rorippa amphobia* (L.) Besser – 6%
		2010	73	*Phleum pratense* L. – 7% *Poa pratensis* L. - 18% *Poa trivialis* L. – 7% *Alopecurus pratensis* L. - 18%	4	23	*Ranunculus repens* L. – 7% *Taraxacum officinale* F.H. Wigg. – 7%
		2011	66	*Elymus repens* L. – 7% *Poa pratensis* L. - 15% *Poa trivialis* L. – 7% *Alopecurus pratensis* L. - 22%	3	32	*Ranunculus repens* L. – 16% *Taraxacum officinale* F.H. Wigg. – 9%
		2012	59	*Poa pratensis* L. - 12% *Phleum pratense* L. – 6% *Poa trivialis* L. – 6% *Alopecurus pratensis* L. - 20%	3	38	*Ranunculus repens* L. – 22% *Taraxacum officinale* F.H. Wigg. – 12%
	NPK	2009	80	*Festuca rubra* L. - 14% *Elymus repens* L. – 12% *Poa pratensis* L. - 17% *Alopecurus pratensis* L. – 17%	4	16	-
		2010	74	*Festuca rubra* L. - 8% *Elymus repens* L. – 6% *Poa pratensis* L. - 16% *Alopecurus pratensis* L. – 17%	3	24	-
		2011	59	*Dactylis glomerata* L. – 7% *Poa pratensis* L. - 12% *Poa trivialis* L. – 7% *Alopecurus pratensis* L. – 18%	5	35	*Ranunculus repens* L. – 15% *Taraxacum officinale* F.H. Wigg. – 6%
		2012	53	*Poa pratensis* L. - 11% *Alopecurus pratensis* L. – 18%	5	42	*Ranunculus repens* L. – 25% *Taraxacum officinale* F.H. Wigg. – 10%
N/III	O	2009	74	*Festuca rubra* L. s. s. – 8% *Dactylis glomerata* L. – 6% *Elymus repens* L. – 10% *Phleum pratene* L. – 6% *Poa pratensis* L. - 21% *Alopecurus pratensis* L. - 19%	1	25	*Taraxacum officinale* F.H. Wigg. – 9%
		2010	68	*Elymus repens* L. – 7% *Poa pratensis* L. - 17% *Alopecurus pratensis* L. - 23%	2	31	*Ranunculus repens* L. – 6% *Taraxacum officinale* F.H. Wigg. – 7%
		2011	59	*Dactylis glomerata* L. – 6% *Elymus repens* L. – 6% *Phleum pratene* L. – 6% *Poa pratensis* L. - 14% *Poa trivialis* L. – 6% *Alopecurus pratensis* L. - 17%	5	36	*Ranunculus repens* L. – 17% *Taraxacum officinale* F.H. Wigg. – 5%
		2012	50	*Elymus repens* L. – 10% *Poa pratensis* L. - 10% *Alopecurus pratensis* L. - 15%	2	48	*Ranunculus repens* L. – 25% *Taraxacum officinale* F.H. Wigg. – 10%
	G	2009	70	*Phalaris arundinacea L.* -6% *Phleum pratene* L. – 8% *Poa pratensis* L. - 20% *Poa trivialis* L. – 6% *Alopecurus pratensis* L. - 16%	5	25	*Ranunculus repens* L. – 8% *Taraxacum officinale* F.H. Wigg. – 9% *Rorippa amphobia* (L.) Besser – 6%

		2010	68	*Elymus repens* L. – 6% *Phleum pratene* L. – 6% *Poa pratensis* L. - 16% *Poa annua* L. – 6% *Alopecurus pratensis* L. - 18%	3	26	*Taraxacum officinale* F.H. Wigg. – 8%
		2011	66	*Poa pratensis* L. - 14% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 19%	2	33	*Ranunculus repens* L. – 20% *Taraxacum officinale* F.H. Wigg. – 7%
		2012	56	*Elymus repens* L. – 8% *Poa pratensis* L. - 12% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 15%	0	44	*Ranunculus repens* L. – 30% *Taraxacum officinale* F.H. Wigg. – 10%
	NPK	2009	80	*Festuca rubra* L. s. s. – 14% *Elymus repens* L. – 12% *Poa pratensis* L. - 17% *Alopecurus pratensis* L. - 17%	4	16	-
		2010	67	*Festuca rubra* L. s. s. – 6% *Phalaris arundinacea L.* -10% *Poa pratensis* L. - 12% *Poa trivialis* L. – 8% *Alopecurus pratensis* L. - 14%	6	28	*Ranunculus repens* L. – 5% *Taraxacum officinale* F.H. Wigg. – 6%
		2011	47	*Poa pratensis* L. - 10% *Phalaris arundinacea L.* -7% *Poa trivialis* L. – 7% *Alopecurus pratensis* L. - 10%	5	40	*Ranunculus repens* L. – 14% *Taraxacum officinale* F.H. Wigg. – 7%
		2012	40	*Poa pratensis* L. - 10% *Alopecurus pratensis* L. - 12%	2	58	*Ranunculus repens* L. – 30% *Taraxacum officinale* F.H. Wigg. – 12%

Source: own work / Źródło: opracowanie własne

In plots fertilised with the highest doses of mineral fertilisers (N/III), the dominating grasses (above 5% share) were composed of: oat grass (*Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Pres), common meadow grass (*Poa pratensis* L.), red fescue (*Festuca rubra* L. s. s.) and coach grass (*Elymus repens* L.). Species composition of dominating grasses was richer in both variants fertilised with manure (O/III) and liquid manure (G/III). In all variants, irrespective of the form of fertilisers, the share of grasses in meadow sward decreased in the years 2011 and 2012. The share of legumes in sward did not exceed 5%. The share of weeds increased in the years 2011 and 2012 due to periodically high ground water levels.

Annual dry mass yields from particular variants differed markedly in 2009 (tab. 2). The lowest yields were noted in the least fertilised variants O/I and NPK/I but were significantly higher in variant G/I. Compared to the lowest yields, those from variant NPK/II and from all most fertilised variants (O/III, G/III, NPK/III) were significantly higher. Compared with the latter, significantly higher yields were found in variants O/II and G/II.

In 2010 the lowest yields were found in variant NPK/I and a distinct increasing trend was noted in many variants belonging to the common homogenous group (O/I, O/II, G/II, NPK/II, G/III and NPK/III). Significantly higher yield compared with that from NPK/I was found in variants G/I and O/III.

As before, the lowest yield noted in the year 2011 was that from variant NPK/I. Marked tendency of increasing yield was recorded in most variants irrespective of the level of fertilisation (O/I, G/I, O/II, NPK/II, G/III and NPK/III) and significantly higher yield was found in variants G/II and O/III.

In 2012 the obtained dry mass yields were similar irrespective of the amount and type of fertilisers being at the same time markedly lower than before. Decreased yields were mainly caused by significant increase in the share of the creeping buttercup (*Ranunculus repens* L.) in meadow sward at higher ground water levels in the years 2011 and 2012.

The contents of nitrate-nitrogen in particular layers of soil profile were largely variable in the first study year (2009) (tab. 3). In both upper soil layers (0-20 and 20-50 cm) of most subplots, irrespective of the form and dose of fertilisers, nitrate contents were higher than in the deeper (50-80 and 80-110 cm) soil layers.

Similarly, four years later (in 2012) significantly higher contents of $N\text{-}NO_3$ were found in both upper soil layers in fertilisation variant N/I irrespective of the form of applied fertiliser compared with layers 50-80 and 80-110 cm. At this level of fertilisation, no increase in nitrate content was found in soil layer below 20 cm in 2012.

Table 2. Dry mass yields in the study period [$t\cdot ha^{-1}$]
Tab. 2. Zestawienie plonów suchej masy w okresie badań [$t\cdot ha^{-1}$]

Years of study	N/I			N/II			N/III		
	O	G	NPK	O	G	NPK	O	G	NPK
2009	6,12a	8,04b	5,75a	9,32c	9,24c	7,62b	8,08b	8,05b	7,81b
2010	7,75ab	8,93b	6,66a	7,89ab	8,53ab	7,81ab	9,14b	7,79ab	8,08ab
2011	7,12ab	6,55ab	6,00a	7,54ab	8,10b	7,31ab	7,91b	7,15ab	7,34ab
2012	6,62a	5,98a	5,96a	6,36a	6,10a	6,15a	6,80a	6,22a	6,36a

*Homogenous groups: Statistica, Tukey HSD test / **Grupy jednorodne: Statistica, Test HSD Tukeya*

Source: own work / Źródło: opracowanie własne

At the second level of fertilisation (N/II) significantly higher contents of nitrates were found in the two upper soil layers in plots fertilised with organic fertilisers both in the beginning and at the end of experiment. This indicates a lack of leaching of nitrates down the soil profile. Mineral fertilisation at this intensity resulted in an increase in $N\text{-}NO_3$ content in 20-50 cm soil layer compared to the top 0-20 cm layer and significantly higher than in deeper soil layers (50-110 cm). However, in comparison with the year 2009 both deeper soil layers were enriched in nitrate-nitrogen by about 40 $kg\cdot ha^{-1}$, which suggests washing out of nitrates down the soil profiles at this level of mineral fertilisation.

Four years of manure application at the highest rate of fertilisation (N/III), the content of $N\text{-}NO_3$ in both upper soil layers was significantly higher than at a depth of 80-110 cm. Fertilisation with liquid manure resulted in significantly higher $N\text{-}NO_3$ content in both upper soil layers compared with 50-80 cm and 80-110 cm layers. Application of mineral forms of fertilisers at this rate ended up with a high content of nitrates in both upper and lower soil layers thus indicating their accumulation and leaching below 100 cm of soil profiles.

After four years of most intensive fertilisation, remarkable enrichment of soil layers below 20 cm depth in nitrate-nitrogen (by about 12 to 75 $kg\cdot ha^{-1}$) was observed irrespective of the form of applied fertilisers.

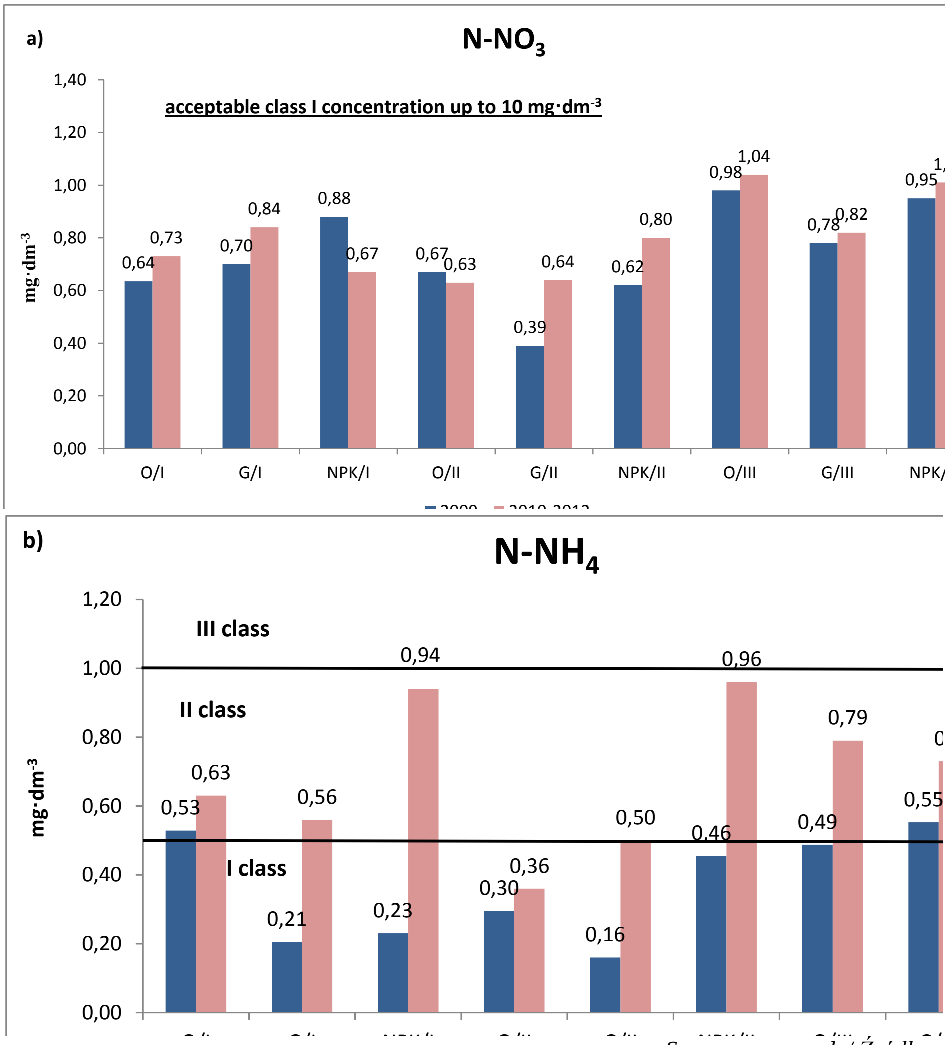
The content of ammonium ions was similar in soil layers in 2009. Significantly higher content was found in 0-20 cm soil layer in variant O/II and in 80-110 cm soil layer in variant NPK/III. After four years of experiment, distinct but equalized increase in ammonium-nitrogen content in soil was noted. This was also an evidence for the leaching of this nitrogen form out of the soil sorption complex. Significant translocation of ammonium-nitrogen down the soil profile was found exclusively in variant G/III.

Table 3. The content of inorganic forms of nitrogen ($N\text{-}NO_3$ and $N\text{-}NH_4$) in particular soil layers [$mg\cdot dm^{-3}$ or $kg\cdot ha^{-1}$ in 10-cm soil layer]

Tab. 3. Zawartości mineralnych form azotu ($N\text{-}NO_3$ i $N\text{-}NH_4$) w poszczególnych warstwach gleby [$mg\cdot dm^{-3}$ lub $kg\cdot ha^{-1}$ w 10 cm warstwy gleby]

Form	Variant	Rate of fertilisation	Year	Soil layers			
				0-20 cm	20-50 cm	50-80 cm	80-110 cm
$N\text{-}NO_3$	N/I	O	2009	31,53b	14,05a	3,71a	1,3a
			2012	13,20bc	15,55c	3,48a	3,51a
		G	2009	27,53c	21,45bc	11,06b	2,82a
			2012	21,61b	18,22b	5,8a	1,04a
		NPK	2009	14,22b	16,00b	10,09ab	5,20a
			2012	12,66ab	14,82b	9,63ab	2,96a
	N/II	O	2009	25,67b	21,82b	7,73a	1,69a
			2012	20,89b	16,25b	4,38a	1,85a
		G	2009	15,71b	3,77a	1,96a	1,11a
			2012	18,75b	20,03b	6,75a	2,76a
		NPK	2009	25,43c	13,7b	3,2a	0,64a
			2012	18,89ab	23,75b	15,75a	11,62a
	N/III	O	2009	17,65b	11,10b	3,22a	1,52a
			2012	17,57bc	26,75c	10,82ab	4,64a
		G	2009	25,16b	19,33b	4,98a	1,30a
			2012	21,83b	20,16b	7,53a	1,82a
		NPK	2009	13,57bc	15,90c	6,02ab	1,39a
			2012	12,47	19,98	14,17	12,47
$N\text{-}NH_4$	N/I	O	2009	1,02	1,22	0,97	0,93
			2012	3,53	4,29	3,44	2,90
		G	2009	0,97	1,54	1,26	0,91
			2012	3,77	3,65	4,49	4,72
		NPK	2009	1,40	1,15	0,99	1,20
			2012	3,51	4,58	4,13	3,65
	N/II	O	2009	3,88b	1,47a	1,04a	1,76ab
			2012	6,25	6,45	7,37	6,54
		G	2009	2,58	2,15	1,12	0,74
			2012	3,02	2,95	5,47	5,72
		NPK	2009	0,94	1,12	1,02	0,86
			2012	3,18	2,97	2,34	3,08
	N/III	O	2009	0,91	0,68	0,53	0,65
			2012	3,68	3,66	4,18	6,35
		G	2009	1,15	1,38	0,64	0,87
			2012	3,39a	3,66a	10,57b	10,13b
		NPK	2009	0,73ab	0,58a	0,76ab	2,14b
			2012	3,04	3,57	3,59	3,03

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 2. Mean concentrations of inorganic nitrogen forms during the study period [mg·dm^{-3}]
Rys. 2. Średnie stężenia mineralnych form azotu za okres badań [mg·dm^{-3}]

A small increase in nitrate-nitrogen concentrations was found in ground water during the study period compared with the year 2009 (fig. 2a), irrespective of the form and intensity of fertilisation. Concentrations of nitrates were near the lower border of the first class of ground water quality [18].

In 2009 concentrations of ammonium-nitrogen in ground water were similar in all variants and fell within the first class of water quality (fig. 2b). During the study period, the quality of ground water in particular plots markedly worsened, irrespective of the type and intensity of fertilisation, and was ascribed to the second class of quality. Ground water in all variants fertilised with mineral fertilisers, irrespective of the dose, and in both variants fertilised with organic fertilisers at the highest rate showed the highest increase in the ammonium-nitrogen concentrations. This was an evidence of nutrient translocation from soil to ground waters.

4. Discussion

Performed studies confirmed the findings of many authors [3, 7, 8, 13, 24] indicating an increase in the share of grasses in plots fertilised with organic fertilisers. Despite small share of tall grasses (important in mown meadows) in sward, application of liquid manure (as in [4]) but also of manure resulted in a favourable slight increase in tall grasses. An important factor modifying the botanical composition of meadow sward manifested by increased share of the meadow foxtail (*Alopecurus pratensis* L.) and creeping buttercup (*Ranunculus repens* L.) and by decline of the common meadow grass (*Poa pratensis* L.) was an increase in soil moisture accompanying the elevated ground water tables, particularly in the years 2011 and 2012 (compare [10]).

Slight increase in yields following increasing rate of fertilisation, despite limited nitrogen release at optimum or excessive soil moisture, confirm results given in [9, 10], which indicated the optimum fertilisation rate of N = 60 kg·ha^{-1}. Irrespective of the rate of fertilisation, organic fertilisers showed higher efficiency expressed in yielding as it was also demonstrated in [2, 4, 7, 8, 12, 23].

Decreased content of N-NO_3 in both upper soil layers in 2012 in all least fertilised variants and in the 0-20 cm soil layer in all variants fertilised at higher rate indicated limited mineralisation and nitrogen release at high levels of ground water as shown by [21] and [10].

Remarkable increase in N-NO_3 content in particular soil layers in 2012, especially in variant G/II and in layers below 20 cm in variants fertilised with NPK indicate poor utilisation of nitrogen [see 19, 22]. Similarly low uptake of nitrates by sward and the increase in their content in 2012, especially in 20-110 cm layers of all variants fertilised at a level of N/III and in some fertilised at a rate of N/II suggests nitrate leaching [16, 17], which pose a threat to ground water quality [6].

Observed in 2012 distinct increase in $N\text{-}NH_4$ content in particular soil layers was a result of nitrate reduction at oxygen deficits [23] caused by high ground water levels. After ground water table decline, due to soil aeration, this form of nitrogen may be oxidised to nitrates, which may be then translocated to ground waters.

Despite increased soil content of both forms of nitrogen in some variants of N/II fertilisation and in all variants fertilised at the highest rate in 2012, the increase in nitrate concentrations in ground water was relatively small and did not result in substantial decrease in water quality [18] as it was also shown in [22].

Concentrations of ammonium nitrogen in ground water (markedly smaller then in peat soil [22]) decreased current standards of ground water quality [18] in variants fertilised with NPK and in all variants fertilised with the highest doses.

5. Conclusions

1. Beneficial changes in the botanical composition of meadow sward consisting in the increased share of valuable (tall) grasses were clearly affected by the use of organic fertilisers, irrespective of applied doses.
2. Increasing share of weeds, mainly of the creeping buttercup, due to high ground water levels and periodical flooding decreased both the amount and quality of yields, particularly in 2012.
3. Fairly high dry mass yields on peat-muck soils fertilised with mineral fertilisers at the lowest rate and their marked increase on soils fertilised with organic fertilisers evidence better utilisation of nitrogen from the latter forms. Distinctly slower growth increments at higher levels of mineral fertilisation indicate poorer utilisation of nitrogen and its leaching down the soil profile.
4. Distinct translocation of both forms of nitrogen in soil, particularly at higher rates of fertilisation and irrespective of the form of fertiliser, resulted in substantial increase in their concentrations in ground water (particularly of $N\text{-}NH_4$) and in the decrease in water quality.

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