Causes of mountain meadow soil chemical degradation in long-term fertiliser experiment

M. Kopeć

Department of Agricultural Chemistry, Agricultural University of Krakow, Poland

ABSTRACT

The fertilising experiment was set up in 1968 on the mountain meadow (720 m a.s.l.) in Czarny Potok near Krynica (20°8' E, 49°4' N). The experiment was conducted on the acid Cambi soil and comprised objects fertilised with two nitrogen forms and two doses against the background of PK fertilisation, the untreated object, and plots with unilateral P and N fertilisation. The paper concerns 30 years of investigations (1968–1997) of the effect of different NPK fertilisation on the dynamic of yields and the meadow sward quality against a background of the same treatments. The dynamic of the botanical composition was presented as well as the dynamic of the grassland yield potential with systematic mineral fertilisation and liming. The application of nitrogen fertilisation with the rate of 90 $N.ha^{-1}$ + PK under mountain conditions and systematic liming of the meadow enables to maintain or increase production over the long period, to decrease the production risk and to prevent degradation of the environment and natural resources.

Keywords: long-term experiment; mountain meadow; fertilisation; sward yields; botanical composition

Sustainability in agriculture denotes an ability to meet demands of contemporary living and not jeopardize the needs of successive generations. Generally, it means the agriculture that will sustain natural resources and protect the environment over an unlimited period of time and among others to limit widely understood grassland degradation. Currently popular radical view assumes a definite switch from intensive to extensive grassland management, which is justified by maintaining diversified biocenoses. However, a postulate of total abandonment of fertilisation or its considerable limitation is highly controversial, as the results would be difficult to predict. Thus, one should consider neither abandonment nor limitation of fertiliser application, but rather necessary improvement of fertilising technologies which would increase its efficiency and at the same time eliminate negative effects, i.e. decline in yield or soil chemical degradation leading to environmental pollution.

An increase of yields and change in botanical composition due to fertilisation are characteristic in the initial period of long-term experiment on grassland. Considerable productive abilities of meadow vegetation and buffer changes caused by fertilisation diminish along with the time of its application. Changes in botanical composition, nutrient cycle, changes in soil physico-chemical properties and in humus content, as well as limiting treatments only to plant cutting may prove the elements of gradual soil degradation and diminishing grassland yield-forming potential. Meadow response to complex cultivation measures is considered as a cumulative effect of those factors (Arnold et al. 1976, Tilman et al. 1994, Piekut 1997).

In the context of these problems, it becomes more important to establish the management system to implement the objectives of sustainable agriculture to limit soil chemical degradation. One must be also aware that it is impossible to achieve the full equilibrium but approximating it is both a process and objective itself (Piekut 1997). Floral wealth and diversity of permanent grasslands are for many reasons their most important resources that fully deserve to be maintained although sometimes it may collide with economic interests.

MATERIAL AND METHODS

The experimental object is situated at Czarny Potok near Krynica, PL (20°8' E, 49°4' N) about 720 m a.s.l. at the foot of Jaworzyna Krynicka in the southeastern part of the Beskid Sądecki massif on land slope 7° and NNE aspect. The experiment was set up in 1968 on a natural mountain meadow of moor mat-grass (*Nardus stricta* L.) and red fescue (*Festuca rubra* L.) type with the large proportion of dicotyledonous plants (*Leontodon hispidus*, *Thymus pulegioides*, *Plantago lanceolata*). The acid Cambi soil developed from Magura sandstone, introducing granulometric composition as light loam (40% of 1–0.1 mm fraction, 37% of 0.1–0.2 mm and 23% of > 0.02 mm fraction) with three characteristic genetic horizons: sod AhA (0–20 cm), browning ABbr (21–46 cm) and matrix BbrC (47–75 cm). The experiment was set up in randomised block method in five replications including eight fertilised plots (Table 1). In the 7th and 8th year, as well as in the 26^{th} and 27^{th} year of the experiment consecutive effects of mineral fertilisers were investigated. During the first break in fertilisation the cultivation measures were limited to cutting and harvesting the sward yields. During the second break in mineral treatment application the sward was grazed by sheep after the amount of harvested yield had been assessed (1 m^2) in the 1^{st} and 2^{nd} cut.

Table 1. The schema of fertilizing in the static experiment in Czarny Potok

Fertilising objects	Annual nutrient rate (kg.ha^{-1})			Nitrogen form
	P	K	N	
0	–	–	–	
PK	39.24	124.5	–	
90 kg Na.n. + PK	39.24	124.5	90	ammonium nitrate
180 kg Na.n. + PK	39.24	124.5	180	ammonium nitrate
90 kg Nu. + PK	39.24	124.5	90	urea
180 kg Nu. + PK	39.24	124.5	180	urea
N	–	–	90	ammonium nitrate
P	39.24	–	–	

In the initial period of the experiment, silicophosphate and 40% potassium salt were used, whereas triple superphosphate and 60% potassium salt were applied after the first break in fertilisation. Since autumn 1985 and with the same level of fertilisation the experiment has been conducted in two series: unlimed and limed (1985, 1995). In the 18th year a half of each plot (21 m^2) was limed with lime containing 80.16% $CaCO_3$ according to the value equal to a half of soil hydrolytic acidity of each fertilised plot. Liming with calcium carbonate in a dose equal to the whole value of hydrolytic acidity in the soil of each fertilised plot was repeated in the 28th experimental year. Dose of 10 kg Cu and 8 kg Mg.ha^{-1} were applied once as regenerative treatment in the 27th year. The vegetation period in the experimental area extends from April to September (150–190 days). Average yearly precipitation during 1968–1997 for the experiment locality (measured at the Krynica meteorological station) was 820.1 mm and 538 mm for the six-month period (April–September), i.e. the time assumed as vegetation period. The amount of precipitation in the region during the year and through April–September did not fluctuate much (respectively variability *V*% = 17.7 and 20.8). The quantity of precipitation in April–September constitutes about 2/3 of total yearly precipitation. Eight times average monthly temperature in April in the experimental area measured during 30 years (1968–1997) was lower than 5°C. Average yearly temperature was 5.7°C and average for vegetation period 11.7°C. Variability of mean monthly temperature during the discussed period was slight, it exceeded 20% only for April, whereas for May and September it was about 10%. Yields of sward green mass were determined twice a year: the first cut was harvested at the turn of June and July (15 June–10 July), whereas the second cut mainly in September (24 August–5 October).

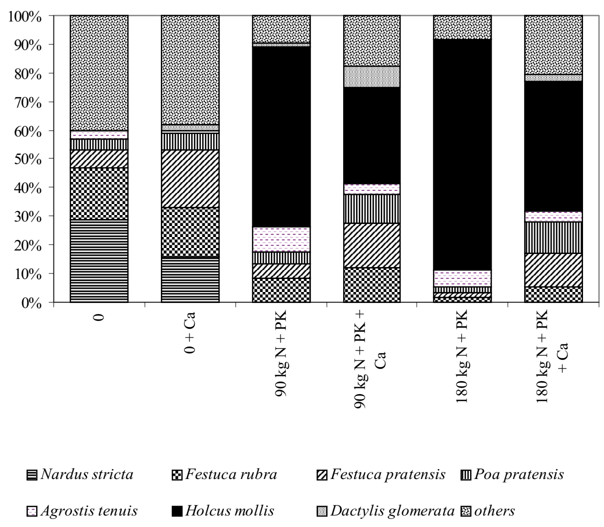

Figure 1. Percentages of leading species in the meadow sward in the limed and unlimed series and two nitrogen doses in 1997

Every autumn after the second cut, soil was sampled for analyses from two layers 0–10 cm and 10–20 cm. The following parameters were determined: pH in H_2O and KCl. hydrolytic acidity with Kappen's method, exchange acidity and exchangeable aluminium using Sokolow's method, available phosphorus and potassium forms with Egner's method modified by Riehm, and finally exchangeable forms of calcium, magnesium, potassium and sodium after extraction with ammonium acetate (pH = 7.0) (Ostrowska et al. 1991). Methodical changes introduced during the 30 years of the mountain meadow utilisation impose an interpretation of results concerning the system of grassland management with particular regard to mineral fertilisation. The interpretation of results presented in this work concerns the static experimental field at Czarny Potok, where long-term experiments on the effect of diversified NPK treatment against the background of the same complex cultivation measures have been carried on since 1968.

RESULTS AND DISCUSSION

The influence of biotopic factors upon the plant botanical composition is considered rather low. Complex cultivation measures, including fertilisation have had far stronger impact on the share of individual species in sward. Increased fertilisation leads to floral changes towards domination of a small number of species, which respond by a quick increase in their output and are more viable under competitive conditions. It also causes simultaneous recession of less productive plants and growing monotony of meadows.

Table 2. Average annual yields of meadow sward dry matter and coefficients of variations (%V)

Fertilising objects*	1968–1985		1985–1997		1985–1997		1968–1997		1968–1997	
	$t.ha^{-1}$	V%	$t.ha^{-1}$	V%	$t.ha^{-1}$	V%	$t.ha^{-1}$	V%	$t.ha^{-1}$	V%
	0Ca		0Ca		+Ca		0Ca		+Ca	
0	2.60	50.4	2.56	28.4	2.73	20.9	2.58	42.5	2.65	40.1
PK	3.85	32.7	4.20	24.0	4.58	24.4	3.99	29.1	4.14	29.9
90 kg Na.n. + PK	6.11	26.1	5.37	26.5	5.34	21.5	5.81	26.6	5.80	25.2
180 kg Na.n. + PK	8.61	34.2	5.65	26.6	5.90	23.9	7.42	38.4	7.53	36.8
90 kg Nu. + PK	5.95	24.4	5.22	24.2	5.49	25.0	5.66	24.8	5.76	24.6
180 kg Nu. + PK	8.17	37.1	5.36	24.1	5.68	25.2	7.05	40.1	7.17	38.7
N	3.84	25.9	4.36	25.8	4.59	20.4	4.05	26.2	4.14	24.8
P	3.39	30.3	3.60	26.0	4.02	26.9	3.47	28.2	3.64	29.6

* see Table 1

Changes in the proportions of prevalent species observed during the 30 years on untreated plot have been small. The proportions of two species, i.e. *Festuca rubra* L. and *Nardus stricta* L. remained the 50% level for the whole first decade of the experiment. Mineral treatment applied at Czarny Potok caused significant changes in the sward botanical composition already in the first three years (Mazur and Mazur 1972). Such violent response of sward species to fertilisation was observed in a majority of experiments (Piekut 1977, Velich and Mrkvicka 1993).

Unilateral application of ammonium nitrate and complete fertilisation increased the grasses proportions in the yield and either eliminated or limited the amount of dicotyledonous, particularly legumes. Phosphorus and phosphorus potassium treatments acted contrary. Fast recession of *Nardus stricta* L. was observed in result of joint application of nitrogen, phosphorus and potassium. However, the species successively increased its share as a result of unilateral N-fertilisation. In the third decade of systematic treatment with ammonium nitrate, the proportion remained on the 60% level. Application of N-fertilisation against PK background (both with 90 and 180 kg $N.ha^{-1}$) led to an increased proportion of *Holcus mollis* in the sward. The rate of the process (and its level) depended primarily on nitrogen dose. Despite continuously increasing share of creeping fog-grass in the sward when 90 kg $N.ha^{-1}$ was applied against the background of PK treatment, there is a basic difference in the rate at which this species share increased as compared to 180 kg $N.ha^{-1}$ dose against the background of PK fertilisation. Favourable floral composition of meadow sward was achieved with NPK treatment including 90 kg $N.ha^{-1}$. The fertilisation stimulated the appearance of valuable grasses, like *Poa pratensis* L. and *Phleum pratense* L. and considerable increase in percentage of *Festuca pratensis* Huds.

In the Czarny Potok experiment liming caused significant changes including mainly more frequent occurrence of useful species in the floral composition (Figure 1). The effect was most pronounced on plots receiving limited mineral treatments, while it was the least noticeable with full NPK fertilisation. Creeping fog-grass on an average decreased its share twice as a result of liming (Figure 1). Dynamic of changes in species proportions in sward has been most variable in time whereas on NPK treated plots liming has caused only slight, i.e. several percent increase in legumes proportions. A similar sward response (increased shares of legumes and valuable grasses in the sward of untreated plots or receiving small doses of $N.ha^{-1}$) was observed in a long-term experiment at Jaworki (Smoroń and Kopeć 1996) and in Rothamsted (Tilman et al. 1994). Plant succession results from both changes in species structure and in soil environment, whose properties would determine the rate of changes and their range.

Fertilisation has had a considerable influence on the yield (Table 2), however no differences were revealed among plots treated with ammonium nitrate and urea for either of the nitrogen doses applied against PK background. The biggest yearly yields, which over 1968–1985 exceeded 8 t $d.m.ha^{-1}$ were obtained with 180 kg $N.ha^{-1}$ + PK treatment. For the successive several years yields bigger than 10 t $d.m.ha^{-1}$ were recorded. During this period, the yield variability coefficient for this nitrogen dose was much higher in comparison to the twice-higher N-dose. The yield obtained with 90 kg $N.ha^{-1}$ + PK was about 6 t $d.m.ha^{-1}$. At that time, the yield from untreated plot was highly variable with small value. A many year average dry mass yield on the untreated plot (2.58 t $d.m.ha^{-1}$) was bigger than stated in literature (Czuba and Murzyński 1993) for similar communities, which results from activating biomass growth through systematic cutting. In case of NPK fertilisation average yield diminished in 1986–1997 (in comparison to 1968–1985).

Treatment with phosphorus and potassium, as well as unilateral fertilisation with nitrogen or phosphorus caused further (1986–1997) increase in sward yield, whereas on plots receiving phosphorous the variability coefficient slightly decreased. Average yields for the 1st and 2nd cuts over the analysed period reveal a set of values proportional to yearly yields but variability coefficients of the 2nd cut were much higher in each case. The fact may be explained by extremely low yields during the period when fertilisation was abandoned.

Meadow sward response to fertilisation level observed in many experiments was similar, although its dynamic depends mostly on site fertility (Gorlach and Curyło 1990, Malhi et al. 1992, Velich and Mrkvicka 1993, Wasilewski 1999). Nutrient doses, particularly nitrogen will depend on site fertility. Generally as a result of increased soil productivity caused by fertilisation, poor sites would be characterised by improved botanical composition, progressively (over c.a. 10 years) increasing yield-forming potential followed by its decline if depleted elements are not supplemented (Czarny Potok, Gorlach and Curyło 1990, Smoroń and Kopeć 1996). On fertile sites, the maximum yield forming potential develops for several years with exclusive NPK fertilisation and then a decline in yields should be expected and its rate will depend in intensity of treatment (Gorlach and Curyło 1990, Krajčovič 1997, Wasilewski 1999).

Generally, it may be said that sward fertilised with 90 kg $N.ha^{-1}$ + PK reveals high stability and adequate macroelement contents. A dose of 180 kg $N.ha^{-1}$ + PK did not significantly diversify the contents of macroelements input with the fertiliser in comparison to twice lower nitrogen dose. The effect of N-treatment on sward mineral composition generally increased after a lapse of several years.

A negative balance between the quantity of nutrients introduced with fertilisers and the amount taken up by meadow sward may be considered beneficial in case of nitrogen as it is most probably connected with high proportion of legumes, mineralisation of accumulated organic matter and precipitation. During the 30 years of the experiment a difference between the amount of nitrogen input with the fertiliser and the quantity of absorbed by plants (Table 3) was –869.4 kg $N.ha^{-1}$ in the unlimed series treated with 90 kg $N.ha^{-1}$ + PK, which means that yearly an average of 29 kg $N.ha^{-1}$ was acquired from other sources than mineral treatment. A tendency to poor acquisition of nitrogen not introduced with fertilizers revealed itself on the plot treated with urea when a double N-dose was used. If in the period before 1985 the result of discussed equation for nitrogen applied in 180 kg $N.ha^{-1}$ + PK dose as ammonium nitrate was –22.5 kg $N.ha^{-1}$, then with the same dose of urea used it approximated 0 (–3.35 kg $N.ha^{-1}$). Since 1986 along with declining yields on the plots receiving higher N doses, the equation result was positive (23.7 kg $N.ha^{-1}$ yearly average with ammonium nitrate treatment and 35.6 kg $N.ha^{-1}$ with urea).

On the plot fertilised with phosphorus and potassium for 30 years, an average of 75 kg $N.ha^{-1}$ was yearly removed with harvest. Only for this type of fertilisation a positive difference was found between the potassium input with fertiliser and the component quantity absorbed by the sward (467.3 kg $K.ha^{-1}$). With full NPK treatment the soil reserves were used up mostly before 1985 and the yearly averages for both applied forms of nitrogen were respectively: –25.5 kg $K.ha^{-1}$ with 90 kg $N.ha^{-1}$ + PK and –56.5 $K.ha^{-1}$ with double N + PK doses.

On all plots receiving phosphorous treatment, a possible increase in soil abundance in phosphorus was observed resulting from this element lower intake by the sward than its input with fertiliser. From 1968 to 1985 a yearly average of 16.7 kg $P.ha^{-1}$ remained in soil of plots treated with 90 kg $N.ha^{-1}$ + PK and 10 kg $P.ha^{-1}$ were left in the plot receiving a double N + PK dose. Over the subsequent period, (12 years) the simplified phosphorous balance on those plots was respectively: 14.1 and 13.5 kg $P.ha^{-1}$. It denotes a possibility to apply considerable phosphorus treatment in this experiment. Even assuming the lowest yearly average increase in the amount of this element (10 kg) connected with the highest yield of sward treated with 180 kg $N.ha^{-1}$ + PK and relatively high sward phosphorus concentration, phosphorus dose in this plot could have been lower than the applied one by 10 $kg.ha^{-1}$, i.e. 29 $P.ha^{-1}$. Positive phosphorous balance in long-term meadow experiments was also confirmed by other authors (Arnold et al. 1976, Gorlach and Curyło 1990, Czuba and Murzyński 1993, Woźniak 1999). Considering the time perspective, the amount of yield and phosphorus contents in plants the phosphorous dose may be limited. Woźniak (1999) and Czuba and Murzyński (1993) (on the basis of 20 year static experiments) as well as Gorlach and Curyło (1990) indicated the importance of balance in determining the component dose.

During the 30 years calcium, magnesium and sodium were taken up in the following quantities: ($kg.ha^{-1}$):

Table 3. The difference between the amounts of nitrogen, phosphorus and potassium introduced with the fertiliser and their amounts uptaken by meadow sward as well as the amounts of uptaken calcium, magnesium and sodium for unlimed series over the period of 30 years

Fertilising objects*	Macroelement ($kg.ha^{-1}$)					
	N	K	P	Ca	Mg	Na
0	–1415.9	–1377.5	–134.8	515.5	171.2	24.9
P	–1897.3	–1539.3	673.0	577.2	213.6	48.0
N	–46.8	–1576.1	–188.6	420.8	230.0	37.1
PK	–2251.7	476.3	629.3	640.0	170.3	44.2
90 kg N + PK	–869.4	–598.1	471.1	701.7	278.7	56.3
180 kg N + PK	123.6	–1148.2	343.3	760.1	395.1	76.5

* see Table 1

Table 4. Average content (mg.kg^{-1}) of cooper, zinc, manganese and cadmium from the last three years of experiment (1995–1997) in the meadow sward from I cut series with and without liming

Fertilising objects*	Cu		Zn		Mn		Cd	
	0Ca	+Ca	0Ca	+Ca	0Ca	+Ca	0Ca	+Ca
0	4.14	3.76	38.8	30.0	154.7	163.1	0.55	0.48
N	5.12	5.63	41.2	32.8	203.5	168.6	0.49	0.54
P	3.98	3.63	37.2	28.7	186.5	143.5	0.80	0.86
PK	3.82	3.81	37.9	25.8	273.3	197.8	0.69	0.52
90 kg N + PK	4.47	4.68	34.3	25.8	205.0	170.8	0.68	0.56
180 kg N + PK	4.90	5.60	35.3	26.4	213.9	160.9	0.81	0.65

* see Table 1

420.8–760.1; 170.3–395.1; 24.9–76.5 in the unlimed series. Plants on plots receiving full NPK treatment took up the least quantities of those elements in the years when the treatment was suspended (with low yields) and particularly in the second year of the break in treatment. A tendency of increased Ca, Mg and Na uptake was observed in the several first years of the experiment, which was connected with considerable raise in yields and also with an assortment of fertilisers applied at that time. Since more concentrated potassium salt and triple superphosphate were introduced the amount of absorbed Na and Ca diminished progressively, which may be explained only as a growing difficulty in these components uptake as a result of soil reserves depletion. Absorption of magnesium was directly proportional to the yield. During the 30 years of the experiment 26% bigger yields were harvested with 180 kg N.ha^{-1} + PK dose as compared to 90 kg N.ha^{-1} + PK dose and at the same time calcium uptake was higher by 8.3%, magnesium by 41.8% and sodium by 35.9%. It suggests a stimulating effect of nitrogen on magnesium and sodium uptake.

Despite regenerative application of 10 kg Cu.ha^{-1} in 1994 copper content in the sward between the 27th and 30th year of the presented experiment was deficient, especially in the 1st cut on plots fertilised with phosphorus and phosphorus with potassium (Table 4). Zinc content was adequate whereas manganese amount was very high. Cadmium content did not exceed limit value for fodder plants (< 0.5 mg Cd.kg^{-1} d.m.) only on the plot unilaterally fertilised with nitrogen in the unlimed series. The content of this toxic element in the sward results from soil abundance and properties, as the fertiliser cadmium input into the soil was lower than its amount removed with harvest. The trace element contents were undoubtedly affected by the yield during the 30 years and by soil properties, particularly its reaction.

However, it is difficult to determine the time when a causative factor of soil sickness reached its threshold value, which causes unfavorable conditions for plant development, as the effect is usually a conglomeration of many elements. Particularly with reference to grasslands changes in soil environment may be noticeable only over a longer time perspective, thus declined meadow yields do not have to be connected with perceptible changes of soil properties. The minimum number of factors related to the effect of production grows in time of specific management system application, finally leading to a complete and negative effect of meadow sward reaction.

Czuba and Murzyński (1993) stated that high doses of NPK applied every year and leading to big yields, already after 10 years caused depletion of soil elements not included in fertilisers until a deficiency of respectively: magnesium, calcium, copper, sodium and zinc occurred. Liming is the most frequently used regenerative measure for degraded soils. Basically, liming does not make up for the loss of nutrients removed with yield, except for calcium and magnesium. However, the measure favors an increase in the amount of available nutrients as a result of change of soil pH and enhancing humus mineralisation. Liming is a specific supplement of mineral fertilisation and should be treated as a starting point to preserve or redress the state of soil environment equilibrium (Woźniak 1999).

Results of Czarny Potok soil analyses concern the period of three years after the second liming (1995–1997), i.e. the 28th, 29th and 30th year of the experiment (Table 5). Mean pH (KCl) values of unlimed soil from the 0–10 cm layer ranged, depending on fertiliser combination, between 3.85 and 4.38 units. The lowest pH values were assessed for the soil from plots receiving the highest N-doses (180 kg N.ha^{-1} + PK). Similar dependencies in the soil reaction have been observed from the first years of the experiment, whereas values measured as the years went by point to growing acidification (Wasilewski 1999, Kopeć 2000). Liming in 1995 caused raised pH (KCl) values. Average values of soil reaction for the three-year period (1995–1997) for the limed series in 0–10 cm soil layer ranged between pH 5.52–5.89. Other authors (Poulton and Johnston 1993) confirmed a beneficial effect of repeated liming upon sustaining the reaction.

Liming caused the biggest changes of hydrolytic and exchange acidity in the 0–10 cm soil layer. Hydrolytic acidity of the 0–10 cm layer soil from NPK fertilised plots in the unlimed series ranges between 6.2 and 7.4 cmol (+).kg^{-1}. Only the soil in the unlimed series from 0–10 cm and from the plot receiving unilateral phosphorus treatment revealed hydrolytic acidity below 6 cmol.kg^{-1}. Liming of the

Table 5. Average values (from there years 1995–1997) and from 1968 year concerning soil acidification and available forms of phosphorus and potassium

Fertilising objects*	pH (H_2O)	pH (KCl)	Hh	Hexch	Alexch	P	K
				cmol(+).kg^{-1}		mg.kg^{-1}	
			0 Ca				
0–10 cm							
1968	5.20	4.38	4.42	0.46	n.d.	4.80	112.1
0	5.24	4.38	5.29	0.56	0.24	10.5	66.1
PK	4.99	3.98	6.80	1.65	1.27	41.1	133.9
90 kg Na.n. + PK	5.48	4.22	6.20	1.22	0.97	36.4	109.8
180 kg Na.n. + PK	4.64	3.85	7.40	2.04	1.68	41.6	97.7
90 kg Nu. + PK	4.91	4.12	7.30	1.41	1.09	43.8	96.9
180 kg Nu. + PK	4.68	3.88	7.35	2.79	2.31	37.1	97.0
N	4.90	4.03	6.31	1.83	1.38	9.07	53.1
P	5.25	4.29	5.54	0.58	0.33	49.1	50.9
LSD $p < 0.05$	0.21	0.15	0.62	0.23	0.12	4.49	11.4
10–20 cm							
1968	5.58	4.48	4.04	0.65	n.d.	2.62	23.2
0	5.86	4.58	4.19	0.44	0.23	7.5	42.8
PK	5.46	4.36	5.16	1.90	1.64	16.6	74.6
90 kg Na.n. + PK	5.44	4.25	4.80	1.20	1.07	11.6	46.4
180 kg Na.n. + PK	5.22	4.10	5.38	2.14	1.88	10.9	40.6
90 kg Nu. + PK	5.53	4.32	5.30	1.66	1.36	13.6	59.5
180 kg Nu. + PK	5.34	4.15	5.29	2.41	2.23	10.6	53.8
N	5.52	4.22	4.73	1.72	1.54	8.63	34.6
P	5.73	4.42	4.22	0.91	0.66	18.7	35.8
LSD $p < 0.05$	0.18	0.14	0.59	0.24	0.16	2.62	7.01
			+Ca				
0–10 cm							
0	6.35	5.89	1.21	0.28	0.10	19.5	62.8
PK	6.09	5.52	1.98	0.47	0.19	48.6	111.7
90 kg Na.n. + PK	6.19	5.56	1.87	0.47	0.24	49.4	84.7
180 kg Na.n. + PK	6.04	5.66	1.78	0.37	0.12	42.2	72.0
90 kg Nu. + PK	6.22	5.80	1.40	0.26	0.11	48.2	82.3
180 kg Nu. + PK	6.15	5.68	1.54	0.32	0.16	40.4	75.2
N	6.30	5.67	1.49	0.23	0.08	16.5	51.9
P	6.27	5.68	1.94	0.19	0.02	41.4	43.2
LSD $p < 0.05$	0.31	0.21	0.13	0.13	0.09	5.36	8.10
10–20 cm							
0	6.29	5.42	3.40	0.73	0.52	5.93	46.9
PK	5.78	4.94	3.94	0.76	0.54	11.2	56.6
90 kg Na.n. + PK	5.76	4.90	4.38	1.00	0.81	10.5	36.7
180 kg Na.n. + PK	5.99	5.03	4.31	1.11	0.93	11.5	45.2
90 kg Nu. + PK	6.37	5.63	3.73	0.46	0.30	9.98	52.3
180 kg Nu. + PK	5.96	4.98	4.26	0.98	0.76	8.72	38.3
N	6.11	5.94	4.01	0.50	0.34	5.88	31.1
P	6.11	5.07	3.88	0.38	0.21	11.3	35.5
LSD $p < 0.05$	0.21	0.15	0.55	0.31	0.18	1.09	5.23

* see Table 1, n.d. = non determined, 1st year of experiment

second rotation lowered the value of hydrolytic acidity almost 3–5 times. Relatively the lowest decrease in hydrolytic acidity under liming influence was determined in the soil from plots unilaterally fertilised with triple superphosphate. No statistically significant differences in hydrolytic acidity values were assessed in soil of limed series from plots treated with 90 and 180 kg N.ha^{-1} + PK.

The greatest effect of liming on a decrease in exchange acidity was detected on plot fertilised with a double dose of nitrogen as urea and receiving unilateral N-treatment. Statistically significant differences of exchange acidity were determined in soil from both tested layers of unlimed series between plots fertilised with 90 and 180 kg N.ha^{-1} + PK. Exchange acidity values in the unlimed series were about 8 times bigger than the values of limed series. The lowest decrease in exchange acidity resulting from liming, but still twice as high as compared to unlimed series was assessed on the untreated plot when singular dose of nitrogen as ammonium nitrate was applied. Liming completely removed exchangeable aluminium. Average for three years values assessed in the 1–10 cm layer did not exceed 0.24 $cmol.kg^{-1}$ of soil and were between 4 and 17 times lower than exchangeable aluminium content in the unlimed series. The results for over three-year period after liming in 1995 show that it had the greatest effect on soil acidification regulation in the 0–10 cm layer. Acidification decreased also in the deeper layer (10–20 cm) and the set of values is similar to the unlimed series.

Liming applied in 1995 caused mobilisation of available phosphorus forms in the soil of the 0–10 cm layer contrary to the 10–20 cm layer where its slight retardation was noticed. As compared to unlimed series, the biggest (almost 50%) increase in available phosphorus influenced by liming occurred in the soil. The content of phosphorus was depleted (0–10 cm level) by unilateral N-fertilisation and on the untreated plot. In the soil unilaterally treated with superphosphate the content of available phosphorus declined by 19% on the 0–10 cm level and by 65% in the 10–20 cm layer. The content of available potassium diminished generally on both levels as the effect of liming. The lowest decline in the content of this form of potassium occurred on the plots and total loss of this element was due to unilateral N-fertilisation and on untreated plots.

Changes of exchangeable cations contents in soil caused by nutrient depletion as result of unbalanced or unilateral fertilisation of the meadow at Czarny Potok have been considerable (Kopeć and Noworolnik 1999). The extent to which the nutrients are depleted is affected by the total yield obtained on individual plots and the level of N-fertilisation (Krajčovič 1997, Woźniak 1999).

Based on investigations using provocative doses of nitrogen on grasslands an opinion has been formed that depending on site and community, nitrogen dose should be about 200 kg $N.ha^{-1}$ on the lowlands whereas in the mountain conditions it should be halved. The costs of measures undertaken to restore productive potential of grasslands degraded by high mineral fertilisation may exceed the profits from increased yields. Grassland renovation with exclusively mineral fertilisers, including microelements, following its many-year intensive utilisation was undertaken only in the experiment conducted by Czuba and Murzyński (1993) and resulted in the expected improvement of the yield and sward quality. However, the input copper dose was considerable (51 kg $Cu.ha^{-1}$ during the 10 year period).

In the Czarny Potok experimental conditions a positive component balance which appeared by the end of the experiment, a slight effect of liming, regenerative treatment with magnesium and copper, or a change in utilisation do not confirm the efficiency of those measures for fast restoration of productive potential. More concentrated fertilisers allow to considerably lowering the costs but the results of their permanent application increase the investment on supplement of components which are not included with fertiliser. Maximisation should not be an alternative for maintaining constant fodder production on a meadow or pasture. This alternative should be provided by different practices and techniques allowing for diversification of the site trophicity. Soil properties and botanical and chemical composition of sward should be basic determinants for fertiliser doses, their chemical composition and method of application.

Studies (Kopeć 2000) conducted on microbiologal activity of soil in Czarny Potok confirm the efficiency of liming on an increase in useful soil microorganisms and contradict microbiological soil sickness in these conditions. Suitability of liming was also confirmed for maintaining stable humus content. Strong soil acidification is connected with big amounts of calcium necessary for it de-acidification which in turn (with a single dose) caused increased mineralization of organic matter and a decrease in soil content of humus in shallow profiles of mountain meadows.

The presented results confirm the thesis that level and stability of production of high-situated meadow communities depends also on complex cultivation measures, mainly fertilisation. In favorable climatic and biotopic conditions the influence of fertilisation on the amount and stability of yields is smaller. The range and purposefulness of complex cultivation measures becomes more important along with the period of time when it affects the ecosystem, its intensity, extreme climatic conditions and worsening of biotopic conditions. High-situated meadow productivity conditioned by uniformity of precipitation should not be intensively exploited, as the use of bioelements in conditions of temporary and hardly predictable lack of water is limited. N-fertilisation of mountain meadow with dose up to 100 $kg.ha^{-1}$ against PK background makes possible maintenance of agroecosystem balance over a long period of time. An excess of components resulting from incomplete utilisation by plants falls within limits that provides no hazards to agricultural environment for a long period of time. Due to permanent removal of nutrients with the sward yield, which has not been considered in fertilisation, studies undertaken to meet nutrient and fertiliser demands of plants concerning magnesium, sodium, and microelements. Deficiency of those elements is a factor limiting productive potential of meadows. Thus, when solely mineral fertilisation of grasslands is applied it is necessary to adapt proper techniques, fertiliser forms, and primarily treatment itself to the rate at which nutrients become taken up by plants. It would lead to optimal grassland utilisation.

REFERENCES

Arnold P.W., Hunter F., Fernandez G.P. (1976): Long-term grassland experiments at Cocle Park. Ann. Agron., *27*: 1027–1042.

Czuba R., Murzyński J. (1993): Wielkość i jakość plonów siana oraz zmiany zasobności gleby w warunkach stosowania dużych dawek NPK w okresie 20 lat. Cz. II. Zmiany zasobności gleby po 20 latach i efekty regeneracyjnego stosowania składników niedoborowych. Rocz. Nauk Roln. A, *110*: 61–68.

Gorlach E., Curyło T. (1990): Reakcja runi łąkowej na wapnowanie w warunkach wieloletniego zróżnicowanego nawożenia mineralnego. Roczn. Glebozn., *41*: 161–177.

Kopeć M., Noworolnik A. (1999): Wybrane właściwości fizykochemiczne gleby w 30 letnim doświadczeniu nawozowym na górskim użytku zielonym (Czarny Potok). Zesz. Probl. PNR, *465*: 559–567.

Kopeć M. (2000): Dynamics of yielding and quality changes of mountain meadow sward over 30 years of fertiliser experiment. Zesz. Nauk. AR Kraków, 267, Rozpr. 84.

Krajčovič V. (1997): Four lines of fifty-year research in grassland agriculture. In: Zbor. Ref. Konf. Ekologické a biologické aspekty krmovinárstva, Nitra: 10–29.

Malhi S.S., Harapiak J.T., Nyborg M., Flore N.A. (1992): Dry matter yield and N recovery from bromegrass in south-central Alberta as affected by time of application of urea and ammonium nitrate. Commun. Soil Sci. Plant Anal., 23: 953–964.

Mazur K., Mazur T. (1972): Wpływ nawożenia mineralnego na plon, skład botaniczny i chemiczny masy roślinnej z łąki górskiej. Acta Agr. Silv., Ser. Agr., XII/1: 85–115.

Ostrowska A., Gawliński S., Szczubiałka Z. (1991): Metody analizy i oceny właściwości gleb i roślin. Kat. Inst. Ochr. Środow., Warszawa: 324.

Piekut K. (1997): Stan zrównoważenia ekosystemów łąkowych w warunkach zróżnicowanej gospodarki wodno-pokarmowej. Wydaw. SGGW, Rozpr. Nauk. Monogr. Warszawa.

Poulton P.R., Johnston A.E. (1993): The Rothamsted long-term experiments-their relevance to modern agriculture. Proc. Int. Symp. Long-term static fertilizer experiments, Warszawa-Kraków: 5–30.

Smoroń S., Kopeć S. (1996): Wpływ zmiennego nawożenia mineralnego na plonowanie łąk górskich w okresie 25 lat. Zesz. Probl. Post. Nauk. Roln., *442*: 395–403.

Tilman D., Dodd M., Poulton P., Johnston A., Crawley M. (1994): The park grass experiment: Insights from the most long-term ecological study. Proc. Conf. Long-term experiments in agricultural and ecological sciences, Cab Int.: 287–303.

Velich J., Mrkvicka J. (1993): Influence of long-term fertilization on development of permanent meadow phytocenosis composition on yielding capacity. Proc. Int. Symp. Long-term static fertilizer experiments, Warszawa, Kraków: 39–46.

Wasilewski Z. (1999): Wpływ długotrwałego i zróżnicowanego nawożenia azotem na produktywność pastwisk grądowych. Wyd. IMUZ, Rozp. Habil.

Woźniak L. (1999): Niektóre ekologiczne i rolnicze uwarunkowania i skutki nawożenia użytków zielonych. Zesz. Nauk AR Kraków, 349, Sesja Nauk., *64*: 331–338.

Received on March 29, 2001

ABSTRAKT

Studium degradace půd horských luk v dlouhodobém výživářském pokusu

Výživářský pokus byl založen v roce 1968 na horské louce (720 m n. m.) v Černém potoku u Krynice v Polsku (20° 8’ východní délky, 49° 4’ severní šířky). Půdou na pokusné lokalitě byla kyselá kambizem, kde byl sledován vliv dvou forem dusíku ve dvou dávkách, PK hnojení a samostatného hnojení P a N. Kontrolní varianta nebyla hnojena po celou dobu experimentu. Cílem pokusu bylo ověřit vliv hnojení během třicetiletého období (1968–1997) na změny výnosu sena a na jeho složení v porovnání s nehnojenou variantou a vyhodnotit účinnost vápnění na sledované parametry. Aplikace N v dávce 90 kg $N.ha^{-1}$ + PK a pravidelné vápnění vedlo k udržení produkce nebo k jejímu zvýšení na sledované horské louce během celého pokusu a minimalizovalo riziko snižování výnosu, degradace půdy a negativního působení na životní prostředí.

Klíčová slova: dlouhodobý pokus; horská louka; hnojení; výnos sena; botanické složení

Corresponding author:

Dr. hab. Michał Kopeć, Katedra Chemii Rolnej, Akademia Rolnicza im. H. Kołłątaja w Krakowie, Al. Mickiewicza 21, 30-120 Kraków, Poland, e-mail: rrkopec@cyf-kr.edu.pl