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CHANGES OF SOIL AGRICHEMICAL CHARACTERISTICS IN PASTURES INFLUENCED BY MINERAL FERTILIZING

S. Hejduk

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Abstract

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Grasslands fertilizing is used for increasing of forage yields and quality and simultaneously for soil fertility maintenance. The aim of this study was to evaluate the effect of mineral fertilizing on basic agrichemical soil characteristics (pH, available nutrients) and soil organic matter at grazing exploitation of grasslands. 60 kg $N.ha^{-1}$ was applied in the year of experiment establishment and 90 kg N, 30 kg P a 90 kg K ha^{-1} in each of following four years. Significantly higher pH (+0.17), available P (+48.5%), K (+15.4%) and organic C (+8.8%) content was found at fertilized treatment. pH value varied significantly during experiment period (range 0.6) and correlated inversely with proportion of white clover in first cut (r = –0.499). Although available K in soil was only on satisfactory level (less than good), K concentration in the forage was even from unfertilized plots higher than physiological requirement of plants. Available nutrient content constitutes only small proportion of total nutrient content: 5.1% at P, 2.1% at K, 12.0% at Mg and 39.0% at Ca.

soil pH, soil organic matter, phosphorus, potassium, calcium, magnesium

Grassland fertilizing is usually used for increasing of forage production and quality, but simultaneously it serves for maintenance of soil fertility. Unlike meadows in pastures most of the nutrients taken up by plant are recycled through animal excreta. However excreta distribution is uneven and on pastures patchy structure emerges due to high nutrient status in places under dung and urine and on the other hand there are parts of sward with nutrient deficiency (Whitehead, 2008).

If animals are not fed during grazing part of the nutrients are lost from pasture ecosystem through retention in animal products which are exported from a farm. The highest retention was found for nitrogen and phosphorus. Farms should endeavour to create management with balanced system for nutrients with good nutrient status in agricultural soils. Balanced nutrient flow is important for high-quality and stable agricultural production but also for maintenance of ecosystem functions (positive externalities) (PILGRIM *et al.*, 2010; MA, 2003). Long term use of physiologically acid fertilizers or fertilizing omission (leading to excessive white clover proportion) can lead to decreasing soil pH and thus soil fertility and ecosystem productivity (BOLAN *et al.*, 1999).

Aim of this study was to evaluate the effect of mineral fertilizing on basic agrichemical soil characteristics (pH, available nutrients) and soil organic matter while grazing exploitation of grasslands.

MATERIAL AND METHODS

The experiment was established in 1995 in extensive managed pasture sward, localized 2 km west of Rapotín (17°0′29″N, 50° 0′13″E) in altitude 400 m a. s. l. Long term sum of precipitation amounts to 727 mm, long term mean annual temperature 6.9 °C. Soil type is cambisol developed on the mica schist deluvium. Clay particles under under 0.002 mm make up 10.1–15.6% of the topsoil (sandy loam).

Original grassland was seeded on arable land in 1985. In April 1995 half of the plots was renovated by rotary cultivator, one quarter was overseeded and the last quarter stayed as permanent unimproved grassland. Original pasture stand belong to the *Lolio–Cynosuretum* association with predominant *Trifolium repens, Lolium perenne, Poa pratensis, P. trivialis* and *Taraxacum sect. Ruderalia*. White clover proportion in swards was evaluated immediately before the first cut on weight basis from the area 1.0 m^2 (8 samples per fertilized and unfertilised treatment respectively within 1997–1999, 4 samples per treatment in 1996).

The grassland was used alternately in such a way that in the first grazing cycle it was mowed and forage was conserved and next three growths were grazed. The stands were grazed by beef breeds and their crossbreeds at a loading of 1.7–2.0 cattle units. ha^{-1}. In the year of the experiment establishment (1995), the swards were harvested by mowing only. Plot size was 50 m^2. Further description of the experiment was published by HEJDUK *et* HRABĚ (2003).

Fertilizing

Since 1996 there were two fertilizer treatments used in the experiment:

1) H_0 – no fertilized variant, without mineral fertilizer use, only excreta from grazing animals.
2) H_1 – fertilized in April at the rate 30 kg N, 30 kg P, 90 kg K and further after 1st and 2nd cut 30 kg $N.ha^{-1}$, total 90 kg mineral N was applied per ha and year.

In 1995 only 60 kg $N.ha^{-1}$ was used for fertilized plots. Mineral fertilizers used in following years were as followed: ammonium nitrate with limestone (27.5% N, 7% Ca), superphosphate (8.0% P, 22% Ca) and potassium chloride (48.6% K).

Soil sampling and analysis

In the period 1995–1999 dynamics of changes of pH (in 0.2 M KCl) and available nutrients (P, K, Ca and Mg) using Mehlich II method was estimated in topsoil layer 0–200 mm. Four soil samples were analysed in 1995 at the end of April during experiment establishment. Eight samples were analysed in 1996 (four from unfertilized and four from fertilized treatment). In the period 1997–1999 each year sixteen soil samples were analysed. Since 1996 the sampling was performed at the end of growing season – in November or in December. All the soil samples were taken evenly through the original and renovated plots.

In the years 1997 and 1999 soil organic carbon (C_{org}) was determined by reaction of suphuric acid and potassium dichromate solution (NELSON *et* SOMMERS, 1982). Additionally in 1997 analyses of pH value in H_2O and SOM quality according to HAYES (1985) were performed.

In 1999 in addition to analyses mentioned above, 8 another samples were taken. They were split in two layers (0–100 and 100–200 mm) and analysed separately. Beside basic analyses pH and available nutrient status C_{org} content was determined. Hereinafter four samples were analysed for available nutrient status (Mehlich II) and simultaneously for total nutrient status (extraction in aqua regia) in 1999. Total nutrient content (P, K, Ca and Mg) was determined in parent rock (schist) after extraction by concentrate sulphuric acid.

Analyses were performed by accredited laboratory of Central institute for Supervising and Testing in Agriculture located in Brno. The statistical analysis was carried out using Statistica vers. 8.0. (STATSOFT, 2007). Differences between treatments were analysed by one way ANOVA at probability level $p < 0.95$. Relationship between soil pH and white clover proportion in swards was expressed by correlation coefficient.

RESULTS

Total nutrient status in topsoil and in parent rock

Concentration and proportion of particular nutrient forms are shown in table I. Potassium had the least proportion of available form from the total nutrient reserve (2.1%). On the other hand the highest percentage of available form was ascertained for calcium (39.0%).

Nutrients content and their proportion in parent rock differ markedly from topsoil (Table I). The greatest difference was found for K (3.7 times higher), for other nutrients the total content in the soil was conversely lower.

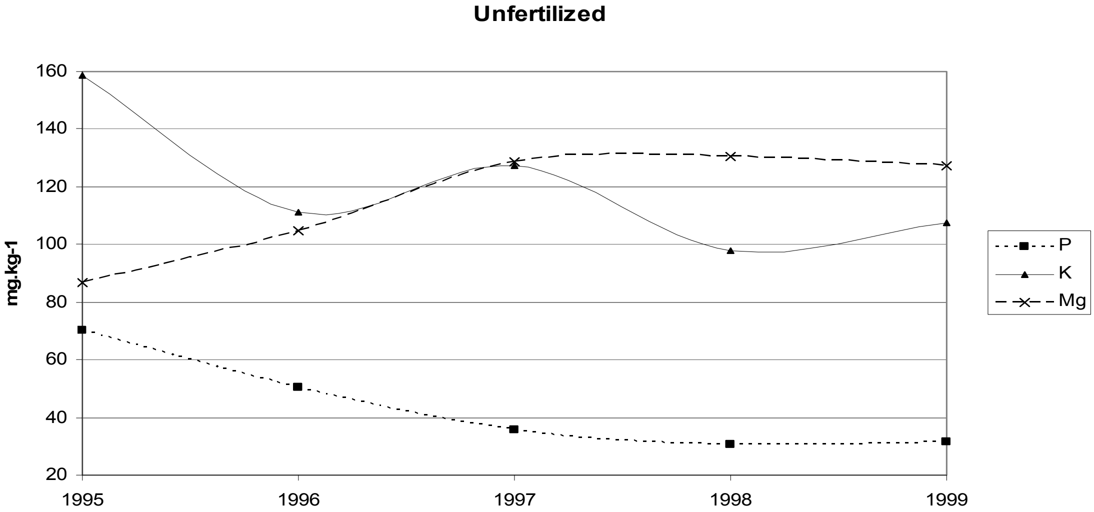
Change of available nutrient content and pH within the experiment period

Dynamic of mean concentrations available P, K and Mg is illustrated in graphs 1 and 2. It is evident

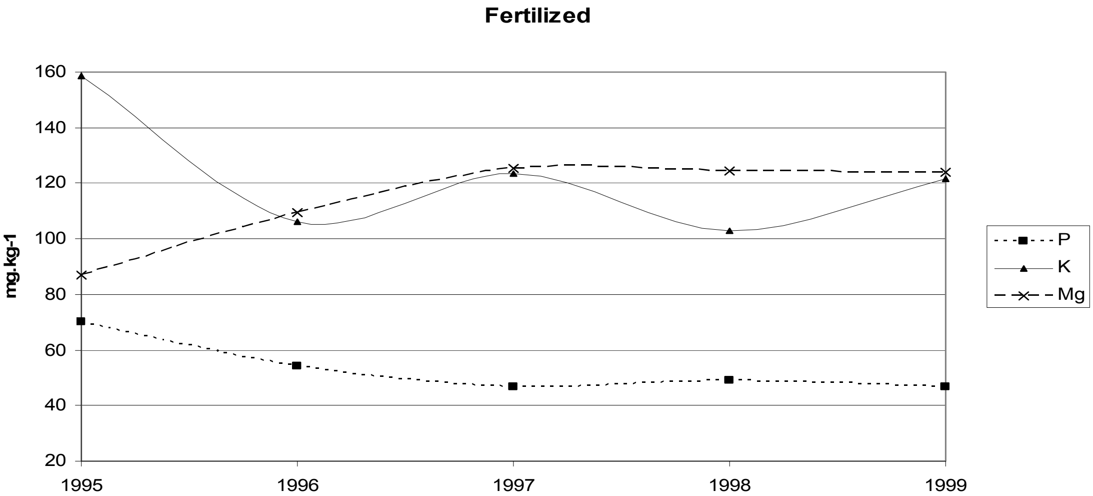
I: *Concentration and soil stock of particular nutrients in soil in the layer 0–200 mm in 1999 (n = 4) and in parent rock (schist, n = 1)*

	$mg.kg^{-1}$ of dry soil			$kg.ha^{-1†}$			$mg.kg^{-1}$ of parent rock
Nutrient	soluble*	available	total**	soluble*	available	total**	total***
P	n.a.	49	970	n.a.	146	2 910	260
K	67	104	5 035	200	311	15 105	18 600
Ca	n.a.	2 142	5 495	n.a.	6 395	16 043	3 330
Mg	n.a.	116	965	n.a.	345	2 880	610

n.a. = mot analysed, † bulk density 1.5 $g.cm^{-3}$ was used for calculation, * in 0,01 M solution of $CaCl_2$, **after extraction of aqua regia, *** after extraction of 96% sulphuric acid



1: *Changes in available nutrients concentrations during experiment period in unfertilized plots (n = 2 in 1995, n = 4 in 1996, n = 8 in 1997–1999); spring sampling in 1995, autumn sampling in following years*



2: *Changes in available nutrients concentrations during experiment period in fertilized plots (n = 2 in 1995, n = 4 in 1996, n = 8 in 1997–1999); spring sampling in 1995, autumn sampling in following years*

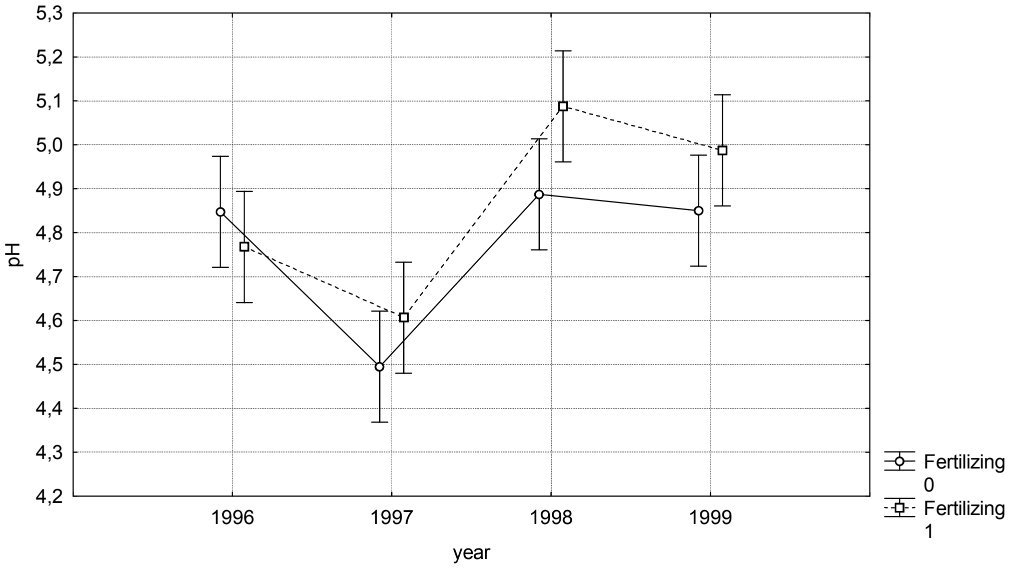
that in the first year there were the highest P and K concentrations in a soil and on the other hand the lowest concentrations of Mg. In subsequent years, available Mg increased in both treatments. P and K decreased in unfertilised soils only.

Figure 3 shows that during the experiment in both treatments considerable pH changes occurred (max. 0.6). With the exception of the year 1996 pH was higher in fertilised plots. In most cases pH is strongly acid (up to pH 5.0). In the whole period 1996–1999 pH was significantly higher in fertilized plots (+0.09; p = 0.044).

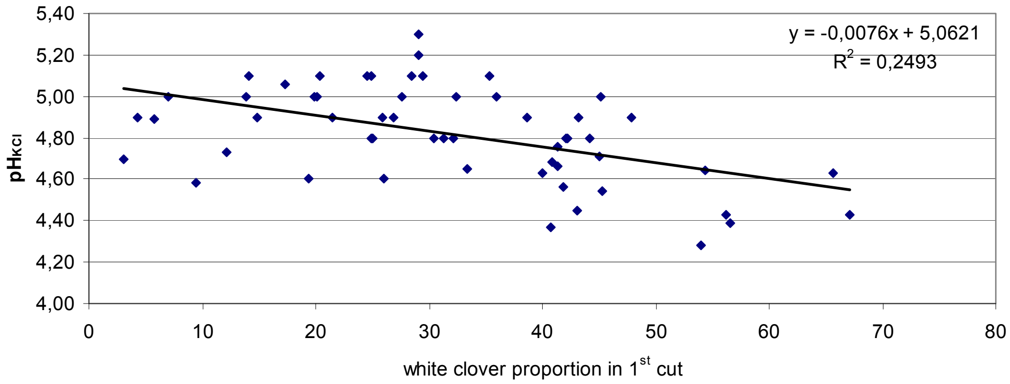
The highest weight proportion of white clover in swards was found on the plots in 1st growth in 1997 (HEJDUK, 2000). In the same year pH value was significantly less then in other years ($p < 0.001$). In the period 1996–1999 significant inverse correlation ($r = -0.499$) between white clover proportion and soil pH (Figure 4).

SOM quality and the differences between pH_{H2O} and pH_{KCl} in 1997

Table III shows substantial differences between both forms of pH (1.15 and 1.07 respectively in unfertilized and fertilized plots. C_{org} content and SOM quality are low. Fulvic acids (FK) markedly predominated over fraction of humic acids (HK). Proportion of humic substances (HK+FK) made up 37.1 and 37.8% of SOM. No significant differences were found between fertilised and unfertilised plots.



3: *Changes of soil pH during experiment period (n = 8 in each year, bars show standard error)*



4: *Relationship between white clover (Trifolium repens L.) proportion in 1st cuts (weight %) and soil pH in individual plots in 1996–1999 (n = 56)*

II: *pH, organic matter content and quality in soil under pasture swards, 1997 (n = 8)*

Treatment	pH_{H2O}	pH_{KCl}	C_{org}	C_{HK}	C_{FK}	C_{HK}/C_{FK}	$(C_{HK}+C_{FK})/C_{ox}$
Unfertilized	5.65	4.50	1.33	0.19	0.32	0.62	0.378
Fertilized	5.68	4.61	1.36	0.20	0.31	0.66	0.371

III: *pH_{KCl}, and a content of available nutrients (mg.kg^{-1}) and C_{org} (g.kg^{-1}) in soil (0–200 mm), 1999 (n = 12; 8 for C_{org}), LSD = least significant difference*

Treatment	pH_{KCl}	P	K	Ca	Mg	C_{org}
Unfertilized	4.84^{a}	33^{a}	105^{a}	1 997^{a}	118^{a}	12.5^{a}
Fertilized	5.01^{b}	49^{b}	121^{b}	2 090^{a}	123^{a}	13.6^{b}
LSD (p = 0.95)	0.12	12.2	16.2	245.5	19.0	0.09

Values followed by the same letters are not significantly different from one another ($p < 0.05$)

Differences in pH, available nutrients status and SOM five years after mineral fertilizers application

Significant increase of pH, available P and K was ascertained in topsoil of fertilised plots five years after application of fertilisers (Table IV). Available Ca and Mg have not changed. SOM increased by 1.1 g.kg^{-1} (p = 0.005).

IV: *Agrichemical characteristics of soil in the two depths, 1999 (mg.kg^{-1}), n = 8*

Soil layer	pH	SOM	P	K	Ca	Mg
0–100 mm	5.13^a	2.89^a	51.1^a	138.4^a	2013.8^a	127.0^a
100–200 mm	4.75^b	1.61^b	36.3^a	81.0^b	1907.5^a	107.6^b
LSD (p = 0.95)	0.20	0.15	16.6	28.1	280.2	15.2

Values followed by the same letters are not significantly different from one another ($p < 0.05$)

There are stated results of soil analysis in two topsoil layers in 1999 in table V. In the upper layer (0–100 mm) significantly higher pH, SOM (C_{org}*1.724) and available K and Mg was ascertained in comparison with v lower layer 100–200 mm. Surprisingly, available P was not significantly different (p = 0.075).

DISCUSION

Total nutrients content in soil and parent rock was distinctively higher than available nutrients in topsoil (Table I and II). Available phosphorus formed 5.1% of total soil P. Most of P was obviously added in soil by storage fertilizing, which was used on arable land before its conversion into grassland in 1985. The least proportion of available nutrient from total content was for K, which is presumably bounded in silica grid. Total K content was the highest from all the analysed nutrients, available reserve in soil was only in satisfactory degree (less than good) in both treatments during the whole period. Small difference was ascertained between soluble and available form for K. It is probably connected with low CEC of the soil.

In the soil there is probably vigorous K release from crystal lattice into soil solution and subsequently prompt uptake by plants. Although the reserve of soil available K is in satisfactory level only in autumn (i.e. less than good), plants take up more potassium (Table V) than serves for their physiological needs even on unfertilized plots (VELICH, 1986; POULÍK, 1996). According to both authors, K concentration in pasture forage should not exceed 28.0 g.kg^{-1} DM. Considerable amount of K which is released from rocks into soil solution described also e.g. HOLMQUIST *et al.* (2003) in Scandinavia. This phenomenon describes likewise VOPĚNKA (1993), who warns against high K fertilizers inputs into soils with low clay content which are frequently overfertilized if we take into account only available K status in autumn period. Good availability of K for plants is reason for low Mg in forage (antagonistic relationship), which can results in health problems of animals, so called grass tetany (KAYSER *et* ISSELSTEIN, 2005; VALLENTINE, 2006). Tetany factor should not exceed a critical value 2.2. Forage from the fertilised treatment surpassed this value in 1998 and 1999 (see Table V) and also in following growths (data not shown).

V: *Nutrients concentration of the forage in the 1st cuts in 1998 and 1999 (g.kg^{-1} dry matter) (Hejduk, 2000)*

Year	Treatment	P	K	Ca	Mg	Tetany factor
1998	Unfertilised	3.0	29.9	4.9	2.5	1.70
	Fertilised	3.5	37.9	3.4	2.1	2.83
1999	Unfertilised	2.9	28.3	5.1	2.5	1.52
	Fertilised	3.8	39.4	3.5	2.2	2.83

High initial values of available P and K status within experiment period (Figure 1 and 2) are obviously related to term of sampling in 1995 (end of April) at beginning of growing period when the nutrients were made available by soil biota and weathering processes during winter period. Grassland sward was not able to take up all released nutrients so early. In following years soil probes were sampled at the end of growing season and it can be the reason for lower values of available P and K. Unexpectedly available Mg increased over the years although it was not present in used fertilisers. It may be connected with more intensive releasing from plant inaccessible forms due to development of soil biota after beginning of grazing in 1996.

Available P was increased in fertilized plots by 46.3% five years after fertilizers use in comparison with unfertilised plots. Despite of P fertilizing, slightly decrease available P occurred during experiment between 1996 and 1999. It can relate with P retention in body of animals and/or precipitation of soluble P with Fe^{3+} and Al^{3+} ions (minerals strengit and variscit) at strongly acid pH. There is 0.67% P contained in cattle bodies (PEARSON *et* ISON, 1987), which means that for mean live weight increment in a year 300 kg per 1 ha only 2.0 kg P per 1 ha is exported. Available P reserves in soil are 146 kg.ha^{-1} and the export by animals mentioned above represents 1.2% per year. Decrease of available P was however 36 and 13 % in unfertilized and fertilized plots respectively. Another explanation can be uneven excreta distribution of animals within grazing area. Animal defecate more frequently in the surrounding of watering-places and in places where supplement feedstuffs are supplied. On the other hand there are other parts of pastures nutrients are predominantly exported. Thus vast oligotrophic grasslands arose in mountains areas in Slovakia. The nutrients were concentrated on limited areas (paddocks) where eutrophic societies have arisen (NOVÁK *et* SLAMKA, 2003).

As is stated by HEJCMAN *et al.* (2007) good available P status in soil is more important for cultural grasses species than nitrogen fertilizing. Very low available P is mostly found in soils under species-rich grasslands (TALOWIN *et* JEFFERSON, 1999), but simultaneously it is connected with low forage productivity and quality.

Figure 3 shows marked changes in soil pH during experiment period. In the same year (1997) when the least soil pH was ascertained the highest proportion of white clover in swards was recorded (55.3 vs. 40.6% in unfertilised and fertilised plots respectively) in first cuts. High legumes proportion leads according to BOLAN *et al.* (1991) to the release of considerable quantities of H^+ cations into rhizosphere in the process rhizobial N_2 fixation which was subsequently reflected in a decline of soil pH. This phenomenon is probably the reason for significant inverse correlation between proportion of white clover and soil pH (figure 4).

The considerable difference between pH_{H2O} and pH_{KCl} in 1997 is probably due to unsaturated CEC. SOM quality was low, which was obviously associated with low pH. In such conditions soil fungi predominate over bacteria and produce less valuable and mobile fulvic acids. Humic substances proportion in SOM was slightly more than 37% and no differences were between both treatments.

After five years of application of mineral fertilizers significant differences were found between agrichemical characteristics in fertilized and unfertilized treatment. There was surprisingly higher pH in fertilised plots although all used fertilizers should cause physiologicaly acidification and their application should decrease soil pH. The opposite findings can be explained by higher SOM accumulation in fertilised variants, which has a buffering capacity (MARTINEC, 2010). Another reason was probably significantly lover proportion of legumes in fertilized plots by 10.5% (HEJDUK, 2000).

SOM and available nutrients are accumulated in grasslands predominantly in top soil layer. It is connected with the absence of mechanical cultivation and with plant litter on the soil surface, which provides a source of organic matter and nutrient cycling (NÖSBERGER *et al.*, 2000). Also number of roots and a microbial activity reach the highest value near the soil surface. pH was increased in subsurface layer 0–100 mm by 0.47 and 0.27 for unfertilised and fertilised variants respectively. Available P and K were always higher in the top soil layer 0–100 mm. Small difference in P status between the layers was probably connected with the arable land history. In typical permanent grassland soils the differences are usually distinctively lower in lower layer in comparison with top layer (e.g. JANČOVIČ *et al.*, 2002).

Grasslands are currently valued also in terms of the accumulation of carbon (SOM) into the soils. In the process of carbon sequestration should reduce the increase of the concentration of the most important glasshouse gas – carbon dioxide in the atmosphere. In the fertilised variants significantly higher SOM was found (2.35 vs. 2.16%) in comparison with unfertilised plots. This difference represents 5700 kg SOM per 1 ha. Given that fertilised swards provided significantly higher forage production (by 20.2% more) and also more underground phytomass (by 9.3%) (HEJDUK, 2000), more intensive organic matter inputs into soil and subsequent accumulation took place. Increased accumulation of SOM in newly established, fertilised grassland confirmed AMMANN *et al.* (2007).

SUMMARY

The aim of the paper was to establish the effect of the use of mineral fertilizers at grazing swards on basic agrichemical properties and soil organic matter (SOM) content. The trial was established on sandy-loam cambisol at altitude 400 m a.s.l. 30 kg N, 30 kg P and 90 kg K.ha^{-1} was applied in April on half plots and then further 30 kg N.ha^{-1} after 1st and 2nd harvest, as a whole 90 kg mineral N.ha^{-1} was applied per year. In the year of trial establishment a trial was fertilised just by N (60 ha^{-1}) and was not grazed. Fertilizing was applied in a period of five years. First cut was used for silage and following harvests were grazed by beef cattle.

During the experiment period soil samples for agrichemical analysis were collected every year from top soil layer (0–200 mm). In last year of experiment, five years after fertilizers application, soil samples were collected separately from two soil layers: 0–100 and 100–200 mm. In addition soil organic matter content was estimated.

Available nutrients content (Mehlich II) in the topsoil constituted only small proportion of total nutrients pool (extracted by aqua regia): 5.1% for P, 2.1% for K, 12.0% for Mg and 39.0% for Ca. There was slow decline of available P and K content in unfertilised plots during the experiment. In contrast available Mg level increased at the same time in both treatments. Despite the only satisfactory level of available K in soil the forage contained higher K concentrations than corresponded with physiological needs of plants. Soil pH was strongly acid and fluctuated during experiment within the range of 0.6. The lowest values were found out in the same year when maximal white clover content was recorded. Significant inverse correlation relationship ($r = -0.499$) was found between white clover proportion in 1st cuts and soil pH value at the end of growing period.

Five years after application of fertilizers a significantly higher pH, available P, K and SOM content was ascertained in fertilized plots in comparison with plots without fertilizing. The difference in SOM was 0.19% (2.35 vs. 2.16%) which corresponds with 5700 kg per 1 ha. Top soil layer (0–100 mm) contained significantly more available P, K, Mg and SOM and had a higher pH in comparison with lover

layer 100–200 mm. The results showed that there are considerable variations in available nutrients content even in unfertilized soils over the years.

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Address

Ing. Stanislav Hejduk, Ph.D., Ústav výživy zvířat a pícninářství, Mendelova univerzita v Brně, Zemědělská 1, 613 00 Brno, Česká republika, e-mail: hejduk@mendelu.cz