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Soil acidification and liming in grassland production and grassland soil fertility in Slovenia

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ABSTRACT

This paper reviews the evidences on grassland soil acidity and liming in relation to soil processes and herbage production. There is also an outline of the present state of soil acidity and acidity-related traits – contents of organic matter (OM), phosphorus (P) and potassium (K) in Slovene grassland. In grassland, soil acidification is an ongoing process under humid climate conditions. It is mainly driven by leaching of nutrients, net loss of cations due to retention in livestock products, use of physiologically acid fertilizers, acid rain and N_2 fixation. This process is reduced by strong pH buffering capacity of the soil and by physiologically basic fertilizers. Acid grassland soils in Slovenia are widely distributed in spite of the fact that 44% of the total land has developed from a carbonate parent material. Of the 1713 grassland soil samples analysed during 2005-2007 45% were regarded as acid ones (pH < 5.5; in KCl), 57% as soils with very low P status (< 6 mg P_2O_5/100 g soil) and 22% as soils with very low K status (< 10 mg K_2O/100 soil). Increased content of soil organic matter was identified for alpine pastures (> 10% OM in 44% of samples), mainly as a result of low decomposition rate. Liming of acid grassland soils did not always reflect in a higher herbage yield. The cause for this inefficiency is plant composition of grassland. Thus, many grassland plants with relatively high production potential have adapted to acid soil conditions. To illustrate the inconsistent liming effect three researches are reviewed. In the first two researches liming along with fertilizer application did not increase the yield comparing to the fertilized control while in the third research the increase amounted 26%. Liming improves considerably botanical composition of the acid grassland (e.g. sward where Common Bent – *Agrostis tenuis* Sibth. – prevails) and thus indirectly affects palatability and nutritive value of herbage. Grassland liming has a weak direct effect on herbage quality – it usually increases content of Ca and sometimes decreases Mg in herbage. The latter effect is rare. In Slovenia, ameliorative liming is advised for grassland soils with pH < 5.0 and maintenance liming for grassland soils with pH < 6.0 (pH in KCl or $CaCl_2$).

Key words: grassland, soil acidity, liming, herbage yield, Slovenia

IZVLEČEK

ZAKISANJE TAL IN APNJENJE V TRAVNIŠTVU TER RODOVITNOST TRAVNIŠKIH TAL V SLOVENIJI

Pregledni članek obravnava kislost travniških tal in apnjenje v povezavi s procesi v tleh in pridelavo travniške krme. Dodan je zgoščen prikaz kislosti ter s tem povezane vsebnosti organske snovi, fosforja in kalija v travniških tleh v Sloveniji. Zakisanje travniških tal je v vlažnem podnebju stalen proces, ki je odvisen predvsem od izpiranja hranil, negativne bilance hranil zaradi odvzema, uporabe fiziološko kislih gnojil, kislega dežja in biotske fiksacije N_2. Zakisanje tal po drugi strani pomembno zmanjšujejo pufrski mehanizmi v tleh in nekatera gnojila. Razširjenost kislih travniških tal v Sloveniji je velika, kljub temu, da ima 44 % zemljišč karbonatno podlago. Od 1713 vzorcev travniških tal je imelo 45 % pH vrednost pod 5,5 (v KCl), 57 % zelo malo fosforja (< 6 mg P_2O_5/100 g tal) in 22 % zelo malo kalija (< 10 mg K_2O/100 g tal). Vsebnost organske snovi je povečana na planinskih pašnikih (> 10 % OS v 44 % vzorcev) predvsem zaradi slabe razgradnje. Apnjenje kislih travniških tal vedno ne poveča pridelka krme. Razlog za to je v travniških rastlinah, ki dobro prenašajo kisla tla, a imajo obenem razmeroma velik rastni potencial. V zvezi s tem so predstavljene tri raziskave, v dveh apnjenje skupaj z gnojenjem ni povečalo pridelka v primerjavi z gnojenimi kontrolami, v enem pa je pridelek povečalo za 26 %. Apnjenje pomembno izboljša botanično sestavo acidofilne travne ruše (npr. ruša s prevladujočo lasasto šopuljo – *Agrostis tenuis* Sibth.) in s tem posredno vpliva na okusnost in hranilno vrednost krme. Neposredni vpliv apnjenja na kakovost krme je razmeroma majhen – običajno poveča vsebnost Ca v krmi, lahko pa tudi zmanjša vsebnost Mg. Slednji vpliv je redek. Za Slovenijo stroka priporoča meliorativno apnjenje travniških tal s pH < 5,0 in vzdrževalno apnjenje tal s pH < 6,0 (pH v KCl ali $CaCl_2$).

Ključne besede: travništvo, kislost tal, apnjenje, pridelek zelinja, Slovenija

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1 INTRODUCTION

Soil acidity expressed as a pH value can importantly influence plant growth in grassland. Much of agricultural plants actively grow in the pH range between 4.0 and 8.5 but not at the same rate throughout the interval (Whitehead, 2000). Optimal pH value for grassland soil has much narrower interval and differs among grassland species. In spite of these differences, there is a uniform optimal pH value for grassland which differs among countries. Different methods for pH determination represent the key reason for this. Therefore it should be taken into account when dealing with a pH soil value. Table 1 shows some recommended soil pH values for grassland in particular countries. The extraction media used for soil pH determination are also denoted.

Grassland soils with non-optimal pH value are usually acid and this is generally true for the situation in Slovenia.

Table 1: Optimal and target pH value for grassland soils in Slovenia and in some other countries.

	pH (in KCl or $CaCl_2$)	pH (in water)	Source
Slovenia	5.0-5.5 (6.0)	–	Leskošek, 1987
Austria	5.0-6.0	–	BMLFUW, 2006
Swiss	–	5.5-6.7	GRUDAF, 2009
Germany	4.7-6.1	–	Wendland in sod., 2011
United Kingdom	–	6.0	DEFRA, 2010
Ireland	–	6.2 (6.5)	Tunney in sod., 2010
New Zealand	–	5.5-6.3	Sparling in sod., 2008

Note: Soil pH values measured in solution of potassium chloride or calcium chloride are very similar, while those values measured in water are higher than the formers. There is no linear correlation between the results of the first two methods and the third one.

2 GRASSLAND SOIL ACIDIFICATION

Acid soils occur mainly in areas with humid climate and are the most widespread in forest and grassland habitats. After von Uexkülla and Muterta's (1995) estimation, the world's area with acid soils counts 3950 million ha. Of this, 67% is covered by forest, 18% by grassland vegetation and 4.5% by arable crops. In addition to climate development of acid soil is also affected by the parent materials. Soils with silicate parent materials are usually more acid than those with carbonate ones. Acidity of the latter soils is of secondary origin and results mainly from leaching of base cations through soil profile. Soil acidification results from mass flow and interrelated biochemical processes in grassland ecosystems. The most important flows consist in one hand of loss of mineral nutrients due to leaching and yield removal and in the other hand of input of matters from fertilizers, rainwater and lithological basis. Chemical processes involved in soil acidifications are mainly occurring during the nitrogen cycling and less importantly during carbon and sulphur cycling.

In general soil acidification is more pronounced on grassland than on arable land. In Europe the main reasons for this accelerated acidification is connected with geographic position, soil properties and management of grasslands. Grassland here prevails in uplands and mountain areas, i.e. the altitude belt between 700 and 1900 m a.s.l. Meadows and pastures in these areas are usually sloping and have porous and shallow soils. It causes these soils to be prone to soil erosion and leaching of plant nutrients (e.g. NO_3^-, Ca^{2+}, Mg^{2+}) through soil profile, thus leading to soil acidification. These shortcomings can also occur in grassland of low-laying areas in Europe.

Soil acidification in the extensive grassland production is partly caused by insufficient fertilizer application. Increased removal of mineral cations with grassland fodder, which is not matched by fertilizer application, leads to the excess of H^+ ions in the soil and consequently lowering the pH value (de Klein *et al*., 1997). Fertilizer application influences on soil pH value when using physiological acid or alkaline fertilizers. The former type (e.g. ammonium sulphate and urea) acidifies the soil while the latter one (e.g. Thomas phosphate) has the reverse effect. Soil acidification may also result from acid rain (pH < 5.6) containing SO_4^{2-}, NH_4^+ in NO_3^-. Among these ions, the ammonium ion is the critical acidification input (Bini and Bresolin, 1998). Austrian experimental results on liming and fertilizer application (Schechtner, 1993) show the importance of these three groups of matter flows for grassland soil pH value. In a 2-cut grassland experiment soil pH ($CaCl_2$) fell from 5.8 to 4.7 in 44 year period under zero fertilizer treatment. In another 4-cut experiment, which was fertilized with recommended amounts, the physiological neutral PK fertilizer and physiological acid fertilizer (N in the form of urea) declined soil pH from original 5.6 to 4.5 and 4.2 respectively in 17 year period.

In addition to mass flow, soil pH affecting processes occur during the cycling of carbon, nitrogen and sulphur (Bolan *et al*., 1991). In the case of the carbon cycle, the source of H^+ ions is carbonic acid, formed by the reaction of CO_2 with water, and carboxylic acids. However, these two sources of soil acidification are less important if the soil is aerated to allow diffusion of CO_2 through air-filled pores (Marschner, 1986). Of the other two cycles, nitrogen cycle is much more important for soil acidification because its cycling within an ecosystem is roughly ten times faster than the sulphur cycling. Besides, NO_3^- for soil acidification compared to SO_4^{2-} is more important due to its higher leaching loss in some soils. Basic cations which leach together with NO_3^- are replaced by H^+ ions on colloids and the soil solution. Hydrogen ions are generated in a ratio 1 H^+ to 1 N in the metabolism of urea to NH_4^+ (ammonification) and then to NO_3^- (nitrification). Metabolism of urea is important factor for higher tendency to acidification of grassland soil compared to the arable one (Whitehead, 2000). It generally occurs to a greater extent under grassland than under arable crops. Important factor for potential acidification of the soil is also biological nitrogen fixation where legumes and rhizobia are involved. In this process assimilation of NH_3 into amino acids (aspartate and glutamate) generates H^+ by their dissociation. In a case study, Bolan et al (1991) calculated the acidification rate for two farms in New Zealand and one in Australia which was caused mainly by biological nitrogen fixation. First two farms grazed their livestock herds on ryegrass-white clover pastures, and the third one did the same on Verano stylo monoculture (*Stylosanthes hamata* L.). Proportion of biologically N_2 fixed in the systems ranged from 91 to 95%. Their results show the net input of H^+ ion into the surface soil in the order of 8 kmol/ha and per year for the first two farms and 1 kmol/ha and per year for the third one. Taking into account a short term pH buffering capacity of 30 kmol/ha for two soil types for Australia it may take 12 years to cause a drop in pH of one unit from 6 to 5 for the New Zealander farms and 30 years for the Australian farms. The importance of biological N_2 fixation is shown by the experimental results of Mengel and Steffens (1982). In their pot experiments, the soil pH value (in KCl) under red clover (*Trifolium pratense* L.), which was completely supplied with N by biological fixation, dropped from 7.2 to 4.5 in 14 month period. In the control, where perennial ryegrass (*Lolium perenne* L.) grew with the addition of ammonium nitrate (NH_4NO_3), the soil pH value remained unchanged. Hydrogen cations required for the decreasing of soil pH value under red clover derived from the plants to the extent of 60%.

In relation to the latter experiment, it should be noted that the proportion of legumes in the sward and N_2 fixation rate are different in grassland practices. In the case when this proportion and/or N_2 fixation are low, the impact on soil pH can be negligible. Also, pH buffering capacity in the soil under field conditions is usually much higher than that in the case of pot experiments. Therefore, the effect of legumes on the soil pH reported by Mengel and Steffens (1982) is hardly probable to occur in the real situation. An example of very high buffering activity can be found in the article of Murphy *et al*. (2005). The results of 32 year field experiment about the impact of slurry application on the cation balance of the grassland soil in Northern Ireland show that the use of extremely high amount of slurry (200 m^3/ha and per year; 4,76 % dry matter, 0,27 % N) did not decrease the soil pH value. Instead, it even slightly increased compared to unfertilized control. In this case, buffering activity of both soil and applied slurry surpassed acidifying activity of nitrogen in excess of crop need in the system.

The ammonia volatilization and denitrification also affect the pH value of the soil. In the first process H^+ ions in the soil increase while in the second one they decrease. The importance of NH_3 volatilization and denitrification for soil pH value is generally difficult to define due to large diversity of measured values obtained experimentally. Much information on these two soil pH factors can be found in the monograph of Whitehead (1995).

3 THE PH VALUE AND RELATED PROPERTIES OF GRASSLAND SOILS IN SLOVENIA

Published data of the Agricultural institute of Slovenia were used for the assessment of grassland soil fertility in Slovenia on the basis of key indicators (Sušin, 2008a, 2008b, 2008c). In a comprehensive survey of soil fertility in Slovenia 1713 grassland soil samples were analysed in the period from 2005 to 2007. Of which 1215 samples were taken from meadows, 323 samples from lowland and hilly pastures and 139 samples from mountain pastures. All of these samples were taken on the depth of 0 to 6 cm. A large number of samples taken and a good dispersion of sampling sites allowed generalized conclusions that refer to the entire country.

As expected, acid grassland soils prevail in Slovenia (Figure 1). Taking into account that the optimal pH (in KCl) for the grassland soil is between 5 and 6 and that good growth of sward occurs also in neutral soils (pH 6.6 to 7.2), it can be concluded that over quarter of mountain pastures (pH < 4.6) and less than one fifth of meadows and of lowland and hilly pastures have an inadequate pH value. All grassland soils placed in the lower part (pH 4.6 to 5.0) of the acid soil class have also an inadequate pH value, but their proportion is not clear from the published data. Increased soil acidity is emphasized in mountain pastures as a result of the geographic position of these pastures, shallowness and permeability of the soil and the low use of fertilizers.

The content of organic matter in grassland soil of Slovenia is mostly within the normal limits (4 to 10%; Figure 1). Mountain pastures are an exception to this, because the organic matter content of almost half of them is more than 10%. The increased organic matter content is associated with drought conditions and cold weather as well as the soil acidity and excreta of grazing livestock. Accumulation of the root material together with other dead plant material in the soil reduces the productivity of sward. The importance of the soil pH for the mineralization of organic matter is showed by Silvertown *et al.* (2006). They found 3% of carbon in the soil layer from 0 to 23 cm in the case of unfertilized sward and sward fertilized with sodium nitrate ($NaNO_3$), where the soil pH was between 5.0 and 5.6. Sward fertilized with ammonium sulphate ($(NH_4)_2SO_4$) with the soil pH between 4.1 and 3.6 contained from 4.8 to 6.6% of carbon, respectively.

Soil acidity in Slovene conditions is a synonym for the poor supply of the soil with plant nutrients. This is especially true for grassland soils (Figure 2). Analysed soil samples were very poorly supplied with available phosphorus, i.e. as many as 58% of samples contained less than 6 mg P_2O_5 per 100 g of soil (AL method). Acidity of the soil contributes significantly to this poor supply of the soil with phosphorus. It is well known that the availability of phosphorus in the acid soil is reduced due to high amount of aluminium cations (Al^{3+}) adsorbed to clay participles (Whitehead, 2000).

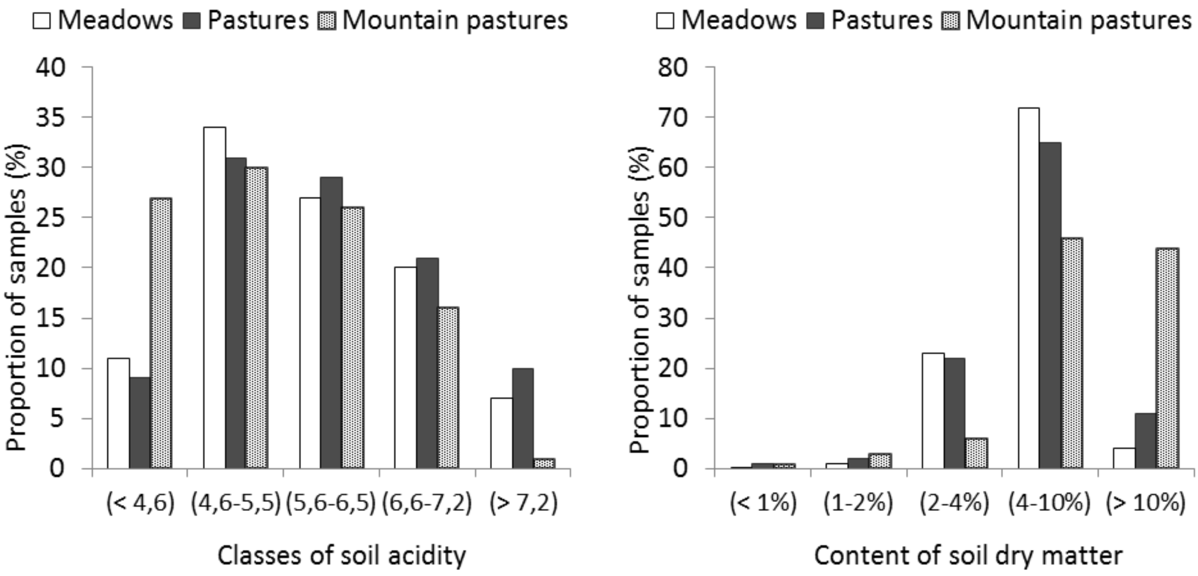

Figure 1: Distribution of soil samples from grassland into 5 categories according to the acidity (pH value) and content of organic matter. The pH classes: very acid, acid, moderately acid, neutral and basic soil. The samples were taken during 2005-2007, n = 1713 (1251, meadows; 323, pastures; 139, alpine pastures; Sušin, 2008a, 2008b, 2008c).

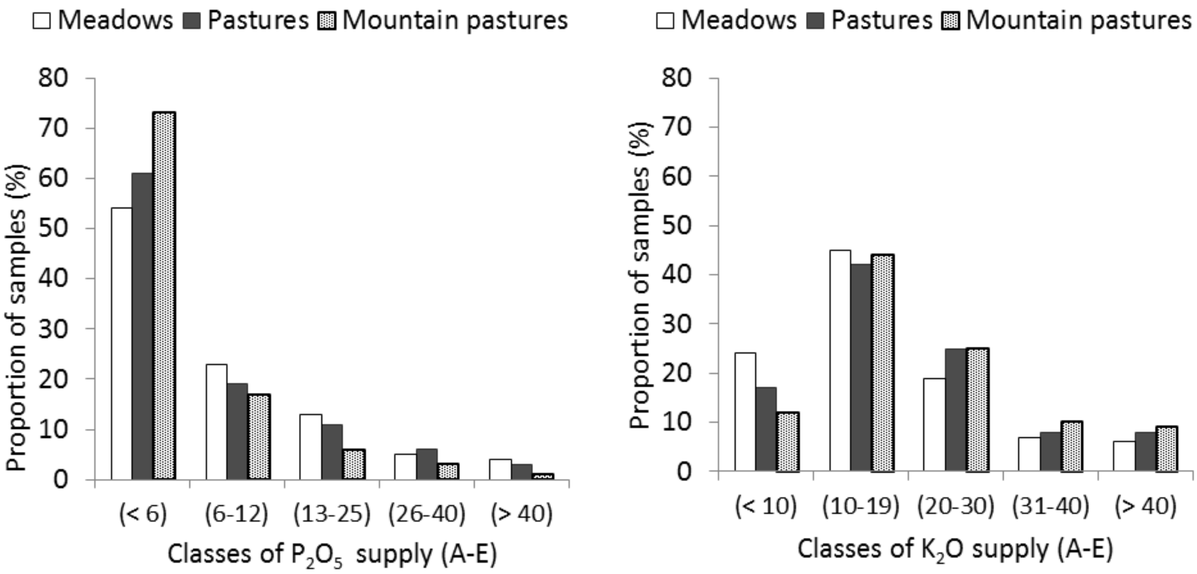

Figure 2: Distribution of soil samples from grassland into 5 categories according to the status of phosphorus (P_2O_5) and potassium (K_2O). The classes: A – low, B – medium, C – optimal, D – excessive, E – extreme. The samples were taken during 2005-2007, n = 1713 (1251, meadows; 323, pastures; 139, alpine pastures; Sušin, 2008a, 2008b, 2008c).

In Slovenia, grassland soils are also relatively poorly supplied with available potassium (Figure 2). Of the analysed soil samples, 21% is arranged in the class of low content of potassium and 43% in the class of medium content. Despite these discouraging findings, the lack of potassium in the soil of Slovene grassland is much less severe than the lack of phosphorus. This is also confirmed by the fact that the uptake of potassium by yield of herbage is higher than one would expect taking into account fertilization and analytically defined potassium content in the soil.

4 INFLUENCE OF LIMING ON GRASSLAND PRODUCTION

Soil liming is the amelioration measure used to improve soil pH value and its structure as well as plant and animal calcium supply. Despite this general benefit grassland liming has variable impact if being judged on the basis of herbage yield (Edmeades *et al*., 1984). The reasons for this uncertainty can be found in the complexity of the interactions between the ground limestone ($CaCO_3$) or lime ($Ca(OH)_2$) and the soil in which the sward plants have important role. Liming increases pH value of soil which affects its physical, chemical and biological characteristics. Soil pH *per se* does not have an important impact on grassland plants. Wheeler *et al*. (1992) established that various pasture species are not sensitive to pH (water) 4.5 with the exception of Harding grass (*Phalaris aquatica* L.) and lucerne (*Medicago sativa* L.). These results had been derived from many solution culture experiments with two pH treatments at zero aluminium concentration (pH 4.5 vs. 5.5; e.g. Edmeades *et al*. 1991).

More important problem for meadow plants growing on acid soils is toxicity of aluminium cations (Al^{3+}) on one hand, and the lack of phosphorous ($H_2PO_4^-$), calcium (Ca^{2+}) and magnesium (Mg^{2+}) on the other. Growth disturbance of grassland plants may also occur in conjunction with other nutrients but is less common. Toxicity of Al^{3+} in grassland soil begins to emerge at pH < 5.5 (measured in water; Wheeler and O'Connor, 1998). Whitehead (2000) states that the threshold of soil pH value for this toxicity is 4.5 (a measuring method is not indicated). Toxic influence of Al^{3+} on grassland plants is reflected in the same manner as in other cultures, i.e. in poorer growth of roots and thus the whole plants. The increased content of Al^{3+} in the soil minimizes the availability of phosphorus to plants, which is often the main negative effect of acid soil on the growth of grassland plants. It seems that this is also the main problem of acid grassland soil in Slovenia.

Liming of acid grassland soil eliminates Al^{3+} toxicity and improves the supply of plants with calcium and phosphorus. But this cannot replace grassland fertilization with phosphorus. Liming accelerates the mineralization of organic matter in soil and consequently improves the plant supply with nutrients, especially nitrogen. Wheeler and O'Connor (1998) report that the total net amount of nitrogen mineralized in the first two years after ground limestone application of 5 and 10 t/ha on the mowing trials was 32 and 68 kg N/ha, respectively.

4.1 Herbage yield

The positive impact of liming on the herbage yield can be expected up to pH (water) 6, as reported by Edmeades *et al*. (1985). However, such positive impact has not been always confirmed even at much lower pH values (e.g. Leskošek, 1987). The results of three experiments are stated bellow in order to illustrate the variable impact of liming on the yield of permanent grasslands.

Leskošek (1987) performed two experiments that involved different fertilization treatments and found that liming along with PK or NPK fertilizers applications had week effect on the herbage dry matter yield compared to non-limed controls (Figure 3). The reason for poor performance of liming is attributed to relatively high pH value compared to the recommendations for grassland soils. This value was before the start of the research, in both experiments, 4.9 (in KCl). At the same time the concentration of exchangeable Al^{3+} ions in both experiments was small. It was 0.96 and 0.25 $mmol_c$/100 g soil in Dragatuš and in Brezje near Ljubljana, respectively.

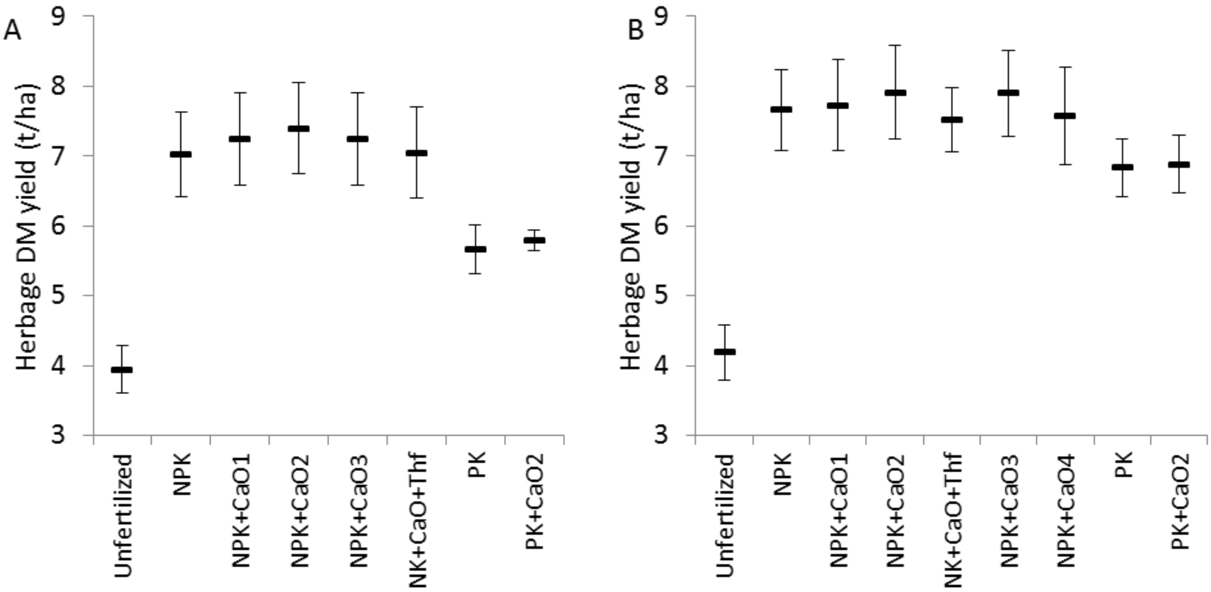

Figure 3: Influence of fertilizer application and liming on the herbage dry matter yield on two 2-cut meadows. The figure shows the annual yields averaged over 5-year period with standard errors of means (Leskošek, 1987).

A, trial at Dragatuš, silt loam, pH_{KCl} 4.9	B, trial at Brezje, silty clay loam, pH_{KCl} 4.9
Unfertilized = zero fertilizers, no liming	Unfertilized = zero fertilizers, no liming
NPK = 40+40 N, 80 P_2O_5, 110 K_2O (all in kg/ha/year,variant b)	NPK = 40+40 N, 80 P_2O_5, 110 K_2O (all in kg/ha/year,variant b)
NPK+CaO_1 = b + 1000 kg CaO/ha (mixed lime)	NPK+CaO_1 = b + 1500 kg CaO/ha (groun limestone)
NPK+CaO_2 = b + 2000 kg CaO/ha (mixed lime)	NPK+CaO_2 = b + 2000 kg CaO/ha (mixed lime)
NPK+CaO_3 = b + 3000 kg CaO/ha (mixed lime)	NK+CaO+Thf = NK as at b + 1500 kg CaO/ha and Thomas phosphate (80 kg P_2O_5/ha/year)
NK+CaO+Thf = NK as at b + 2000 kg CaO/ha and Thomas phosphate (80 kg P_2O_5/ha/year)	NPK+CaO_3 = b + 2000 kg CaO/ha (quick lime)
PK = as at b	NPK+CaO_4 = b + 2000 kg CaO/ha (ground limestone)
PK+CaO_2 = as at b + 2000 kg CaO/ha (mixed lime)	PK = as at b
	PK+CaO_2 = as at b + 2000 kg CaO/ha (mixed lime)

Schechtner (1993) also reports about the poor performance of liming. He conducted two experiments on a high-mountain pasture – *Nardetum* association. In one he compared the effect of different amounts of mixed lime within the PK fertilization and in the other the effect of different amounts of mixed lime within the NPK fertilization (Figure 4).

The influence of liming was expressed only when compared the PK fertilization to the implication of the maximum amount of mixed lime (990 kg CaO/ha every second year) during the period from the fifth to the ninth year of the trial. As for all other comparisons, the increase of herbage yield due to liming was very low regardless the period of comparison. There were two reasons for poor impact of liming: the first one was the grassland community itself, which was difficult to improve and the second reason was the methodological approach since they used Thomas phosphate for phosphorus fertilization that contents calcium in the form of salt and oxide. For this reason both controls (PK and NPK) as well as other treatments received 135 kg CaO/ha per year from Thomas phosphate, meaning that it masked almost all liming influence. This disturbance in trial caused by Thomas phosphate was obvious also in the development of pH values in soil. The implemented amount of 135 kg CaO/ha finally increased pH (KCl) value on around 5 which already provided relatively favorable conditions for growth of grassland species.

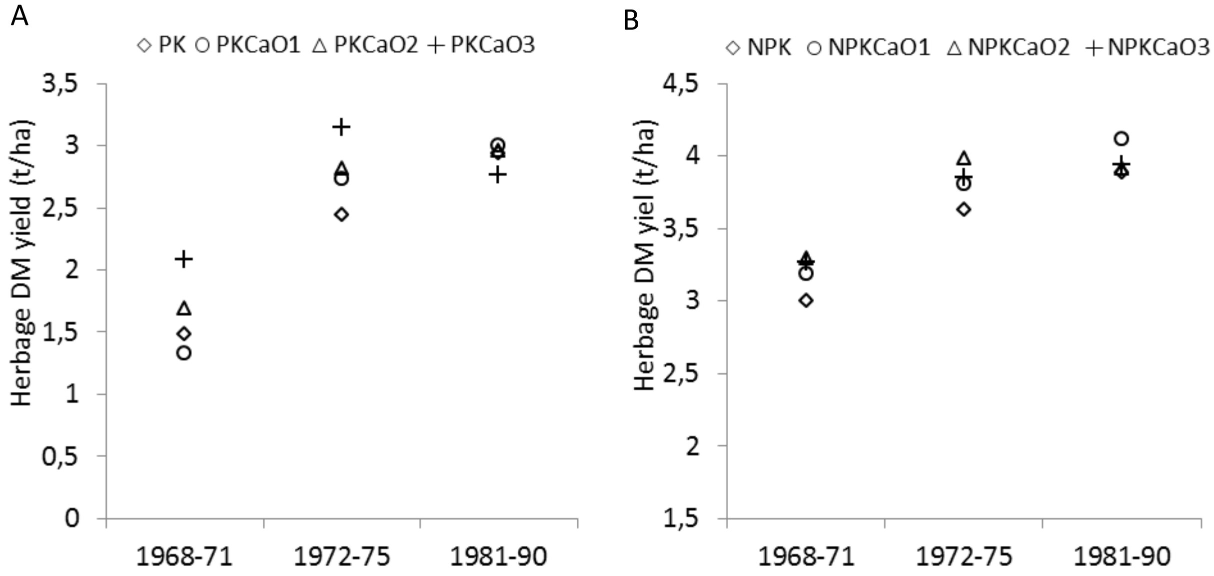

Figure 4: Influence of fertilizer application and liming on the herbage dry matter yield on a poor pasture belonging to the *Nardetum* association (locality: Zachenschöberl, 1300 m a.s.l.). The figure shows the mean annual yield for three periods (duration of the experiment: 1964-1984; Schechtner, 1993).

PK = 300 kg Thomas phosphate (45 % CaO) + 200 kg /ha/year potassium chloride (40 % K_2O); PK application is the same in all treatments
CaO_1, CaO_2, CaO_3 = 500, 1000, 1500 kg/ha (mixed lime, application each second year)
Rates of CaO/ha/year: 135 kg (PK), 300 kg (CaO_1), 465 kg (CaO_2), 630 kg (CaO_3)
N = 2 × 40 kg/ha (KAN, application in spring and after the first cutting)

Unlike the two above described trials, Grundler and Voigtländer (1979) report on good impact of liming using physiologically acid NPK fertilizer (Figure 5). Using this fertilizer liming increased average hay yield in the whole period (1954–1974) for 1.8 t/ha per year i.e. 26 %. At the same time the final soil acidity decreased indicating high liming activity of slag. The research shows that implementation of lime to physiologically acid fertilizer had strong effect on botanical composition of sward. Physiologically alkaline NPK fertilizer had similar effect. The original sward with prevailing red fescue (*Festuca rubra* L.), thread rush (*Juncus filiformis* L.), quaking grass sedge (*Carex brizoides* L.) and Yorkshire fog (*Holcus lanatus* L.) changed due to the impact of above stated factors into a sward with prevailing meadow foxtail (*Alopecurus pratensis* L.), meadow and red fescue (*F. pratensis* Huds.) and Yorkshire fog.

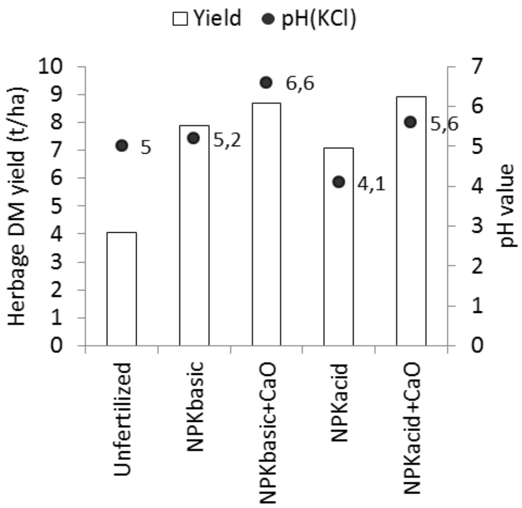

Figure 5: Influence of fertilizer application and liming on the herbage dry matter yield on a permanent pasture at Niedersteinnachu (soil type: gley; pH_{KCl} 4,2; Grundler in Voigtländer,1979). The figure shows the annual yield averaged over 1954-1974. Till 1967, 2-cut system was applied after that it was changed to 3-cut system. pH shown in the figure refers to 1974.

Unfertilized = zero fertilizers, no liming
NPKbasic = basic NPK (rate per ha: 30 kg N/cutting + 80 kg P_2O_5/year + 160 kg K_2O/year), variant b
NPKbasic+CaO = b + 9 applications of CaO (1955-1972, annual rate 1 t CaO/ha), variant c
NPKacid = acid NPK, rate as at b
NPKacid+CaO = acid NPK + CaO as at c

4.2 Herbage yield quality

In acid soil (pH ≈ 4; in KCl) liming together with fertilizer application improves the sward botanical composition and consequently nutritional value of herbage. Both ameliorating measures are needed to obtain optimal growth conditions for grassland plants that do not strive well on acid and poor soil. Example of such improvement is stated in the previous paragraph (Figure 5). Based on a 109 years long field trial in Rothamsted, that is still going on, Thurston (1969) reports about major differences in sward botanical composition connected to the soil pH value. Fertilizer application of physiologically acid ammonium sulphate ($(NH_4)_2SO_4$) caused soil acidity (pH ≈ 3.8; in water). In the sward with this treatment, prevailing species was common bent (*Agrostis tenuis* Sibth.) followed by less abundant red fescue and two other acidophilic species common sorrel (*Rumex acetosa* L.) and creeping cinquefoil (*Potentilla reptans* L.) which were rare. In lime-treated sward with soil pH value of about 5.3 higher quality species throve, especially the most abundant meadow fox tail. There was also a lot of common dandelion (*Taraxacum officinale* F. H. Wigg). Even though liming together with fertilizer application improved sward species composition in many experiments it did not have major influence on the proportion of legumes in swards (e.g. Grundler and Voigtländer, 1979; Leskošek, 1984; Edmeades in *et al*., 1990; Schechtner, 1993).

Liming also affects directly the quality of herbage from grasslands but to a lesser extent. It can increase phosphorus uptake and content in plants due to increased mineralization of organic matter in soil and better availability of mineral bound phosphorus in soil (Wheeler and O'Connor, 1998). Root growth is improved due to decrease of Al^{3+} ions caused by liming. This consequently improves phosphorus supply to the plant. Liming usually increases calcium content in herbage. This is reported by several sources (e.g. Whitehead, 2000; Wheeler, 1998). In two field trials on grassland with original pH value 5.1 and 5.5 (in water) application of limestone at rate of 8 t/ha increased herbage calcium content from 5.0 to 6.1 g/kg of dry matter (Stevens and Laughlin, 1996). But this is not very important, because the control value itself is already high. Liming can have also the negative impact on grassland forage quality. Wheeler (1998) noted the negative impact of liming (5 and 10 t of ground limestone/ha) on content of exchangeable magnesium in soil and on magnesium content in herbage, but this lower content was still appropriate. He also cites the finding of an increase in grazing tetany due to late autumn liming.

5 CONCLUSIONS

Soil acidity in meadows and pastures is often too high for good growth of grassland vegetation. The reason for this is not pH *per se*, but increased content of Al^{3+} in the soil which has negative impact on plants. The content of Al^{3+} is also linked to the restricted availability of phosphorus to plants. Other disturbances in the growth of grassland plants on acid soils are less important. Considering the soil pH value, it is necessary to know the method of its measuring, because it influences on the results considerably. Methods of measuring pH values in the soil represent the key reason for the differences among the optimal values cited in literature.

Grassland soils in Slovenia are often too acidified and very poorly supplied with phosphorus. The situation is the worst in mountain pastures due to management of the grassland as due to adverse pedo-climatic conditions. The latter increase the loss of plant nutrients from the rhizosphere and upper soil layers.

Liming has a number of beneficial effects on soil fertility and also contributes to the better supply of plants with calcium. Nevertheless, liming of acid grassland soils (pH ≈ 5; in KCl) does not always increase the yield of herbage, which has been confirmed by many researches. The reason for this is in particular grassland plants which tolerate the acid soil conditions and have quite a high production capacity as well. In such situation, the herbage yield can be increased simply by adequate fertilizer application to 7 to 9 t dry matter/ha which is quite good. Here, the quality of herbage is also improved in terms of increased proportion of better grasses in the sward. On grassland with very acid soil (pH < 4.5; in KCl) liming is required to improve botanical composition of sward which does not meet yield and quality standards in the managed grassland. At the same time liming of very acid soil improves the supply of plants with some nutrients, especially with phosphorus and nitrogen.

Direct impact of liming of grassland soils on herbage quality is small. Normally, this measure increases the content of calcium in herbage, but it is generally less problematic in the diet of livestock. Due to dilution effect the content of other mineral nutrients in herbage is changed slightly by liming although their uptake is increased. Liming can even worsen the supply of animals with magnesium, although this risk is low.

In Slovenia, liming of grasslands is recommended on acid soil with pH below 5.0, but also on soils wit pH below 6.0 (measured in KCl or $CaCl_2$). In the first case, liming increases the yield and quality of herbage and in the second case it prevents the acidification of soil. Liming also improves the soil structure which may reduce soil compaction on grasslands due to animal trampling and use of heavy machinery. For liming, ground limestone has the advantage before lime and ground dolomite.

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