Fertilizing and liming in a heather area of Norway

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ABSTRACT: In a 6 years' field experiment in a podzolized heather area in Norway the effects of liming and P and Cu fertilization were tested versus changes in vegetation and soil chemistry. The vegetation altered slowly, particularly the woody species, but pronounced over years. Liming had a positive effect on all species except *Deschampsia flexuosa* and *Vaccinium myrtillus,* P tended to favour all except *V. myrtillus*, and Cu promoted all except *Nardus stricta*, *V. oliginosum* and *V. myrtillus.* Surface spreading of liming material and fertilizers caused distinct lime, phosphorus and copper effects and interactions in the soil litter layer. Liming markedly increased pH and Ca level and stimulated microbial activity, whilst the fertilizers increased P and Cu availability in soil. Cu fertilization counteracted a feared Cu deficiency when liming marginal soils. Gradually the changes penetrated into deeper soil layers. This strong chemical influence led the podzol into a cambisol cycle, characterized by retention of humus in the E layer, accompanied by a slight increase in pH, elevated levels of Kjeldahl-N, AL dissolved and exchangeable Ca, and in CEC and BS.

Keywords: heather; liming; fertilization; phosphorus; copper; vegetation; podzol; soil chemistry

The use of remote grazing land has long traditions in Norway, but overgrowing of vegetation, acidification and loss of nutrients by leaching have reduced the quality of our heather areas and mountain plateaux. Nutrients are also bound in increased humus layers, and reduced availability of P combined with acidification has stimulated the growth of the toxic lily plant *Narthecium ossifragum* L. in slopes of blanket mires (peaty land).

Parallelly the modest grass *Nardus stricta* L. is favoured, whilst the nutritive grass *Deschampsia flexuosa* L. has been depressed.

In many mountain valleys farmers have wanted to improve the grazing quality of the heather areas, using fertilizers and soil amendments. Simultaneously it was requested to avoid measures which could lead to eutrophication and harm to water systems. Therefore, N and easily soluble P should normally not be applied, and we tested the effects of slow release fertilizers and amendments (Erstad, Steffensen 1999).

MATERIAL AND METHODS

At the mountain farm Gjesdalsstølen, 600 m above sea level in Jølster parish, Sogn and Fjordane county, a liming and fertilization experiment was carried out in 1991–1996 to amend grazing land quality and to investigate soil changes in a heather area with an iron humus podzol. The experimental area was fenced to protect it against grazing animals.

In addition to zero treatments a calcitic liming material was added at 2 levels, 1 and 2 tons CaO equiv./ha, and P and Cu fertilizers at 1 level, 40 kg P/ha and 25 kg Cu/ha, respectively.

The liming material was a coarsely ground Precambrian marble (0–2 mm), with NV(CaO) = 55 and effective neutralizing value 40/50 ± 3 after 1 year/5 years.

The copper sulphate was a commercial product for agriculture, and was included due to an expected fear of Cu deficiency when liming.

The raw phosphate applied was delivered from Israel (Negev Phosphates Ltd.) with the following characteristics (Table 1).

The experiment was 3-factorial with liming on major plots and 3 replicates. Every late summer the field was botanically analyzed and plants favourable to grazing were harvested and chemically analyzed. Soil material was sampled by plots and pedogenic layers for analyses in 1991, 1993 and 1996.

Table 1. Chemical and sieve analyses of the raw phosphate used in the field trial in Gjesdalen

Chemical analyses, dry sample		Sieve analysis	
		(mm)	(%)
P (%)	14.93	> 2.0	0.3
Ca (%)	40.1	1.0–2.0	0.9
Mg (%)	0.16	0.5–1.0	2.8
F (%)	3.9	0.25–0.5	14.5
Cl (%)	0.03	0.125–0.25	42.1
Cd (mg/kg)	16	0.063–0.125	32.8
Acid insoluble (%)	0.34	< 0.063	6.6

RESULTS

Impact on vegetation

Liming (at two levels) had a positive effect on all species with exception of *Deschampsia flexuosa* L. and *Vaccinium myrtillus* L., P showed a positive non-significant trend to favour all expect *V. myrtillus* L., and Cu promoted all except *Nardus stricta* L., *V. oliginosum* L. and *V. myrtillus* L.

Table 2 presents effects of the amendments on each plant species.

Molinia caerulea L. advanced in the field as time passed, because it benefits in general from all liming and fertilization. The largest amount of lime mineralized nitrogen from the organic pool in soil, and this species utilizes it very well.

Deschampsia flexuosa L. gained most from multilateral fertilization and liming, and also from P and Cu alone.

Nardus stricta L. as established can take up and use all nutrients, but will be suppressed by other species by competition in a fertilized environment, as shown by the 3-way interaction lime × P × Cu.

Empetrum nigrum L. was modest in nutrition requirements and the combinations including P did not stimulate its growth and development.

V. oliginosum L. and *V. myrtillus* L. also had low demands for fertilizers and liming, and in particular the latter had a very negative response. *Vaccinium vitis-idaea* L., however, appears on fields exposed to clear-cutting and fires, and benefits from mineralized nutrients. Soon it will be overgrown by higher plants in a succession.

The response from *Calluna vulgaris* L. must be interpreted carefully, as it declined due to summer dry periods and ageing as well as the effects of the amendments. Anyhow, it is gradually repelled in a changed soil chemical environment.

Fig. 1 shows the effects of main factors and their interactions on the development of the 8 main plant species.

The plant stimulating interactions of lime, P and Cu became apparent, in particular when P was included, but also lime and P alone contributed positively. Fertilization and liming enhanced yields of grazing plants as an overall effect – with the effect of time as decisive factor.

Table 2. GLM Manova test for influence of liming material, fertilizers and year on main species of plants on experimental site 1991–1996, Gjesdalen in Jølster. Characteristic vector stated with Wilks' lambda as test criterion

Variable	*Molinia caerulea* L.	*Deschampsia flexuosa* L.	*Nardus stricta* L.	*Empetrum nigrum* L.	*Calluna vulgaris* L.	*Vaccinium uliginosum* L.	*Vaccinium myrtillus* L.	*Vaccinium vitis-idaea* L.
Lime	0.0224	–0.00569	0.00612	0.00183	0.00133	0.00223	–0.00658	0.000443
P	0.0137	0.000543	0.00396	0.00653	0.00329	0.00672	–0.00190	0.00259
Cu	0.0111	0.00884	–0.000871	0.00377	0.00110	–0.000519	–0.00458	0.00466
Lime × P	–0.0151	–0.00471	0.0124	–0.00208	–0.000964	–0.000688	0.000463	0.00410
Lime × Cu	0.0123	0.00484	0.00939	0.00645	0.00319	0.00268	–0.00123	0.0103
P × Cu	0.0371	–0.0019	0.00300	–0.00129	0.00247	0.00424	0.00145	–0.00466
Lime × P × Cu	0.0148	0.00178	–0.00345	0.00377	0.00189	0.00606	0.000391	0.0134
Year	0.0199	–0.00296	0.00266	0.00561	0.00437	0.000893	0.00143	0.00357

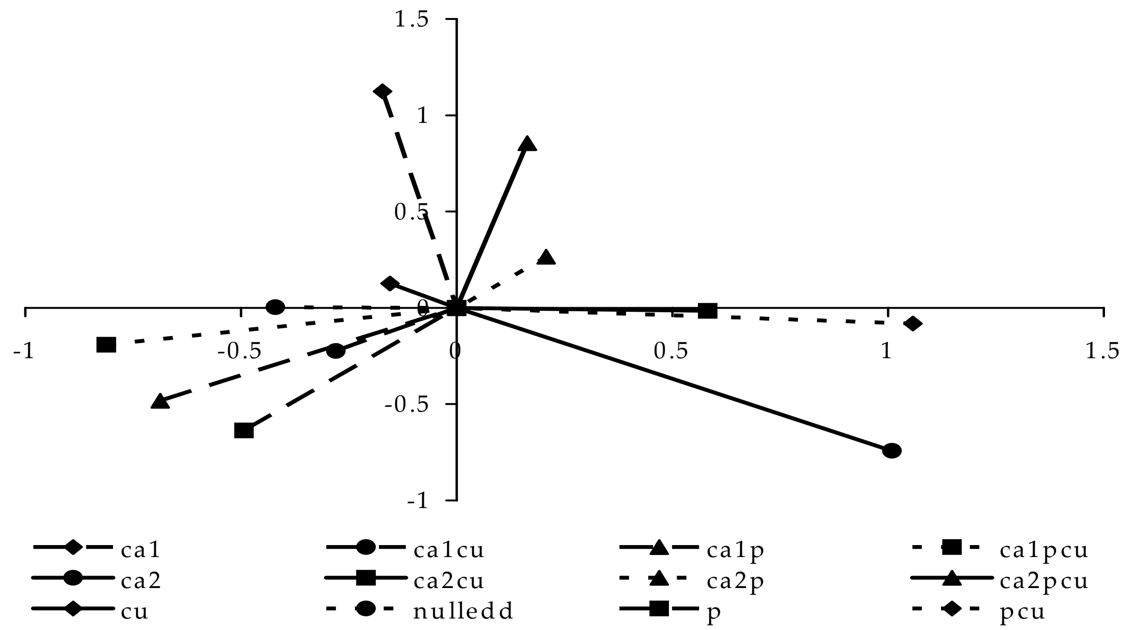

Fig. 1. Effects of fertilization and liming (main factors and interactions) on development of the 8 main plant species in a vector graph, Gjesdalen in Jølster 1991–1996. The plant species withdrawn from the graph to enhance the interactions (nulledd = zero treatment)

From other field experiments it is known that when grazing animals are involved, the effects will come even sooner, because soil will be mixed, organic residues mixed into mineral layers by penetration of feet, thus enhancing the turnover of nutrients in cycle. Additionally animals will add manure to the soil-plant system.

In general the covers of mosses and lichens were reduced over years, mainly due to lime and partly in combination with P.

Chemical contents of grazing plants

Fig. 2 presents the P contents of the plant materials in co-variation with lime and Cu.

It became clear that lime bound the phosphates due to elevated pH and Ca contents. *Vice versa* P had little effect on Ca availability, because the mass of Ca dominated. Fertilizer Cu enhanced the plant uptake of Cu, was hampered again by liming, but promoted by P addition, which probably interacted with the lime.

Changes in soil chemistry

In soil there were distinct chemical effects in the litter layer O_l. Both lime, phosphorus and copper showed strong effects, and the interactions between these measures, changes in general soil chemistry and the relation to biological activity was so profound that it could be measured in both humus layers, O_l and O.

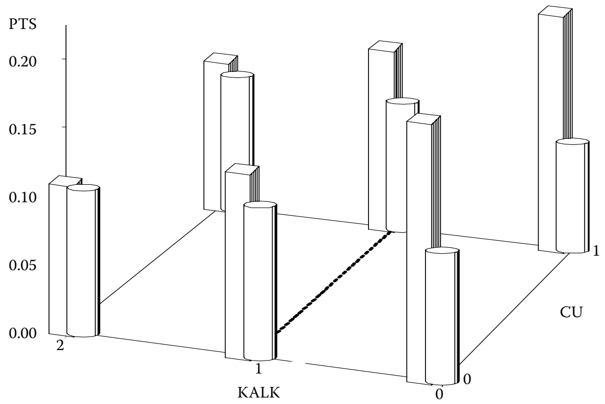

Fig. 2. Average contents of phosphorus (PTS, % DM) in harvested plant materials as a function of added copper sulphate, raw phosphate and liming at two levels. Gjesdalen in Jølster 1991–1996. For Fig. 2 to 5: Pillars – No P, Prisms – P added, Kalk – Lime

pH increased markedly by liming, as expected and shown in Fig. 3.

P fertilization markedly increased the P-AL values in the humus layers, but the effect was gradually hampered by increasing liming (Fig. 4). A new formation of freshly precipitated apatite could by anticipated.

Cu was strongly bound in the upper layers, with clear effects on EDTA extracted Cu values (Fig. 5).

The changes were perceived gradually in deeper layers, too, and surprisingly the chemical influence was so fierce that the podzolization itself was stopped, and we could confirm the start of a cam-

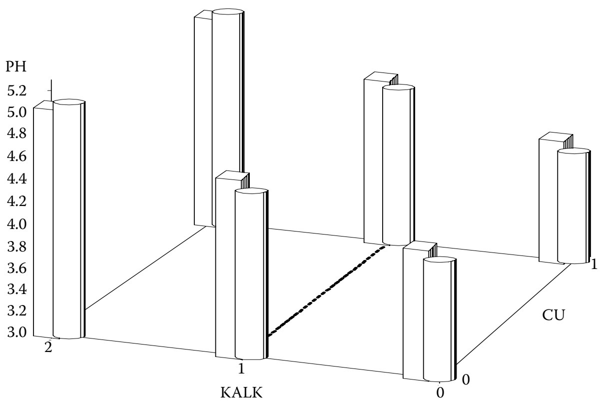

Fig. 3. Average pH of the litter layer O_l during the years of experiment as a function of added copper sulphate, raw phosphate and liming at two levels. Gjesdalen in Jølster 1991–1996

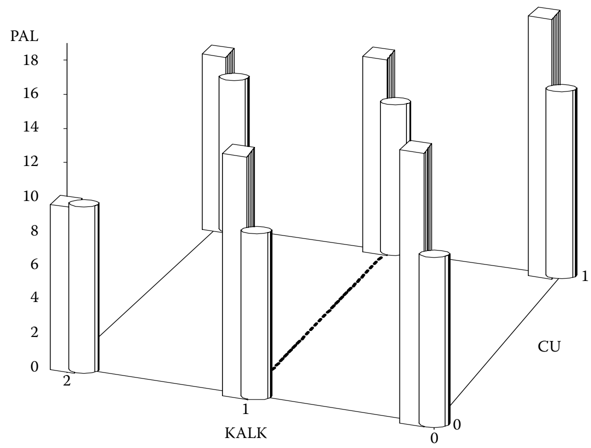

Fig. 4. Average P-AL levels (mg/100 g) of the litter layer O_l during the years of experiment as a function of added copper sulphate, raw phosphate and liming at two levels. Gjesdalen in Jølster 1991–1996

bisol cycle. Characteristic of this was the retention of humus in the leached E horizon, accompanied by a substantial increase in Kjeldahl-N, and the basis of this process was an alkalinization measured as increased pH, AL (ammonium lactate) dissolved and exchangeable Ca, and moreover an elevated cation exchange capacity and base saturation, but really with no decrease in exchangeable H. The E layer was increasingly buffered.

Lime penetrated also slowly into the precipitation horizon B_{sh}.

The formation of Cu-phosphate-carbonate complexes slowed down the migration into the profile. Na, K and Mg were exposed to Ca antagonism, and

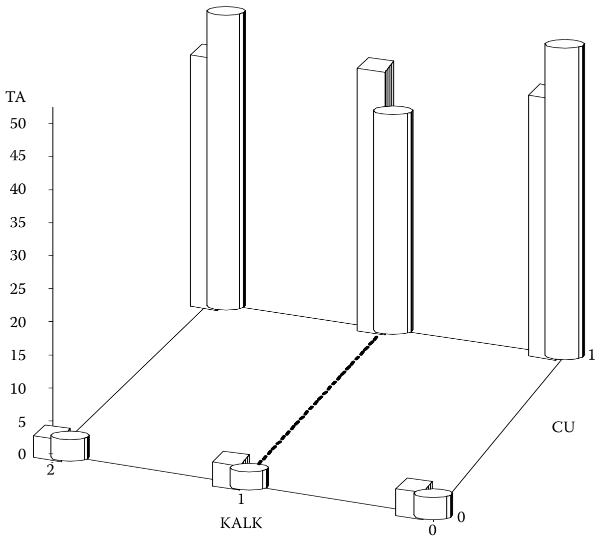

Fig. 5. Average Cu-EDTA levels (mg/kg) of the litter layer O_l during the years of experiment as a function of added copper sulphate, raw phosphate and liming at two levels. Gjesdalen in Jølster 1991–1996

were expelled from soil colloids and leached. K and Mg were also prone to plant uptake and nutritional circulation by repeated litter fall.

DISCUSSION

The interactions between nutrients at plant uptake were complicated. The effects of lime and mineral nutrients were not unilateral, but the cations exhibited an antagonistic behaviour, precipitations were likely in forms as Ca and Cu phosphates, and Cu carbonate. Cu was organically bound to humus complexes. The amendment led to a microbial decomposition of humus, leading to mineralization and competition for N and probably P between microorganisms and higher plants. The stimulated biology yielded a more rapid turnover of nutrients.

Soil chemical co-variations were strong, and they were most apparent in the upper layer (O_l). The graphs visualize the effects, which in most cases could be well interpreted in terms of soil chemistry, biological circulation and leaching processes. The regression models which were established, demonstrated a high level of explanation (R^2).

CONCLUSION

The effects of liming and fertilizing with P and Cu became clearer as the 6 years' experiment proceeded. The effects on vegetation were gradually more pronounced, and the soil chemical changes in the soil profile were more extensive than previously expected. The most decisive was the precipitation of humus in the E horizon, accompanied by a slight increase in pH, AL soluble and exchangeable Ca, and increases in CEC and base saturation. These were all necessary co-factors.

The composition of plant species gradually became more favourable in the aspect of grazing animals, too. Under all circumstances *Molinia caerulea* L. will benefit from easily available N, in this case mineralized N. So far *Deschampsia flexuosa* L. did not advance rapidly, but was stimulated by lime and P in combination. Obvious negative correlations between P and Cu were found, observed as less effect on vegetation, probably due to formation of precipitates. A more balanced addition of amendments (lime × P × Cu) was favourable for most species, with a clear exception for *Nardus stricta* L., which competes best on sites of a low nutrient status. The same concerned the modest *Empetrum nigrum* L.

V. oliginosum L. and *V. myrtillus* L. have very low requirements for fertilizers and liming, the latter demonstrated a very negative response. *Vaccinium vitis-idaea* L. appeared, however, to benefit from mineralized nutrients, as we also know it pops up on fields exposed to clear-cutting and fires.

References

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Vliv vápnění a hnojení na vřesovišti v Norsku

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ABSTRAKT: Byl zkoumán vliv vápnění a hnojení P a Cu během šestiletého experimentu na podzolovaném vřesovišti v Norsku ve vztahu ke změnám vegetace a chemismu půdy. Vegetace se měnila pomalu, zejména dřeviny, byla však během let markantní. Vápnění mělo příznivý účinek na všechny druhy s výjimkou *Deschampsia flexuosa* a *Vaccinium myrtillus,* P měl tendenci podporovat všechny druhy kromě *V. myrtillus* a Cu příznivě působila na všechny druhy s výjimkou *Nardus stricta*, *V. uliginosum* a *V. myrtillus.* Povrchové rozprostření materiálu pro vápnění a hnojení mělo za následek výrazný účinek vápna, fosforu a mědi a vzájemné působení ve vrstvě hrabanky. Vápnění nápadně zvýšilo hodnotu pH a Ca a podnítilo mikrobiální aktivitu, zatímco hnojiva zvýšila dostupnost P a Cu v půdě. Hnojení Cu působilo proti obávanému deficitu Cu při vápnění marginálních půd. Tyto změny postupně pronikaly do hlubších vrstev půdy a silný chemický vliv přivedl podzol do cyklu kambizemě charakterizované retencí humusu ve vrstvě E, doprovázené mírným zvýšením pH, zvýšenou úrovní Kjeldahlova N, rozpustného Al a výměnného Ca a zvýšením CEC (výměnné kapacity kationtů) a nasycením bází.

Klíčová slova: vřesoviště; vápnění; hnojení; fosfor; měď; druhová skladba; podzol; chemie půdy

Byl zkoumán vliv vápnění a hnojení P a Cu během šestiletého experimentu na podzolovaném vřesovišti v Norsku ve vztahu ke změnám vegetace a chemismu půdy. Vegetace se měnila pomalu, zejména dřeviny, byla však během let markantní. Vápnění mělo příznivý účinek na všechny druhy s výjimkou *Deschampsia flexuosa* a *Vaccinium myrtillus,* P měl tendenci podporovat všechny druhy kromě *V. myrtillus* a Cu příznivě působila na všechny druhy s výjimkou *Nardus stricta*, *V. uliginosum* a *V. myrtillus.* Povrchové rozprostření materiálu pro vápnění a hnojení mělo za následek výrazný účinek vápna, fosforu a mědi a vzájemné působení ve vrstvě hrabanky. Vápnění nápadně zvýšilo hodnotu pH a Ca a podnítilo mikrobiální aktivitu, zatímco hnojiva zvýšila dostupnost P a Cu v půdě. Hnojení Cu působilo proti obávanému deficitu Cu při vápnění marginálních půd. Tyto změny postupně pronikaly do hlubších vrstev půdy a silný chemický vliv přivedl podzol do cyklu kambizemě charakterizované retencí humusu ve vrstvě E doprovázené mírným zvýšením pH, zvýšenou úrovní Kjeldahlova N, rozpustného Al a výměnného Ca a zvýšením CEC (výměnné kapacity kationtů) a nasycením bází. Účinky hnojení a vápnění P a Cu byly výraznější, jak tento šestiletý experiment pokračoval. Vliv na vegetaci byl postupně markantnější a změny chemismu v půdním profilu byly rozsáhlejší, než se očekávalo. Rozhodující byla precipitace humusu v horizontu E doprovázená mírným zvýšením pH, rozpustným Al a výměnným Ca a zvýšením CEC (výměnné kapacity kationtů) a nasycením bází. To všechno byly nezbytné spolufaktory.

Rovněž druhová skladba rostlin se postupně stávala příznivější z hlediska pastvy zvířat. Za všech okolností bude mít prospěch *Molinia caerulea* L. ze snadno dostupného N, v tomto případě mineralizovaného N. *Deschampsia flexuosa* L. dosud rychle nepokročila, byla však povzbuzena kombinací vápna a P. Byly zjištěny zřejmě negativní vzájemné vztahy mezi P a Cu, pozorované jako menší vliv na vegetaci pravděpodobně z důvodu vytváření precipitátů. Vyrovnanější přidávání doplňků (vápno × P × Cu) bylo prospěšné pro většinu druhů s výjimkou *Nardus stricta* L., která konkuruje nejvíce na stanovištích s nízkým stavem živin. Totéž se týkalo skromné šíchy *Empetrum nigrum* L.

V. uliginosum L. a *V. myrtillus* L. mají velmi nízké požadavky na hnojiva a vápnění, přičemž *V. myrtillus* projevovala velmi negativní reakci. *Vaccinium vitis-idaea* L. však měla prospěch z mineralizovaných živin, protože víme, jak se náhle objevuje v oblastech vystavených holosečím a požáru.

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