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Annual Research Report

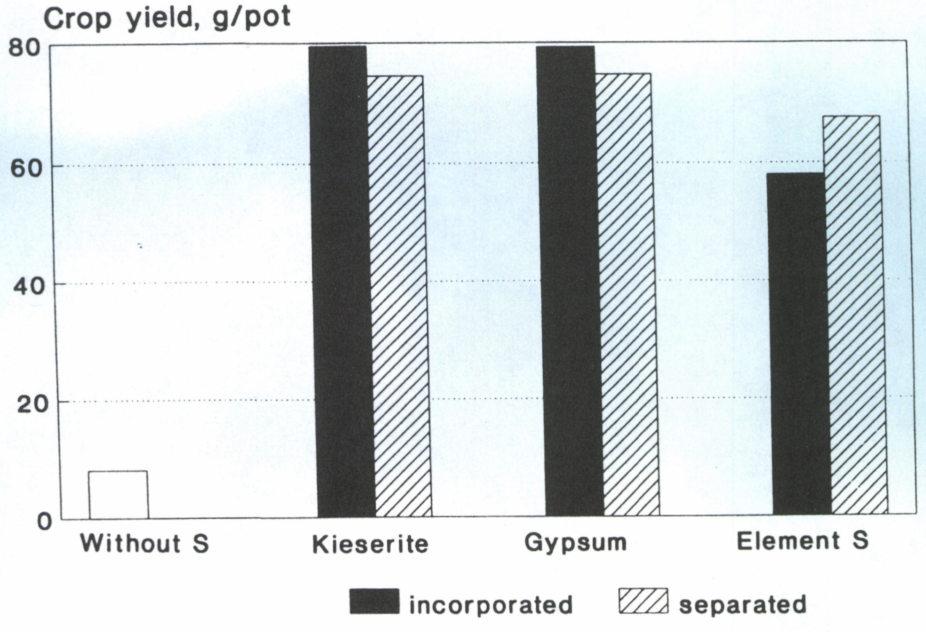
1993

Fertilizer Research Programme

(IJVF - Norsk Hydro a.s.)

Effects of different fertilizers and fertilizer materials on crop yield and on mineral content

Leif Ruud



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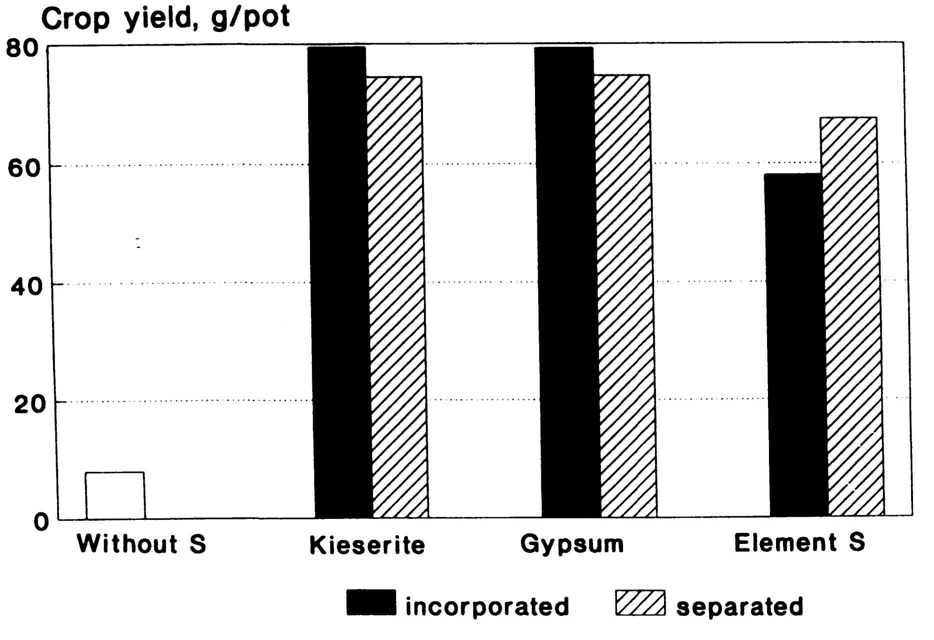

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Sammendrag:

This report describes det results of the greenhouse and field experiments conducted in the cropping season of 1993 by the Department of Soil and Water Sciences, Agricultural University of Norway, in cooperation with the Norsk Hydro a.s. The experiments involved 9 different series, in which the effects of different fertilizers and raw materials on dry matter or grain yields and on mineral concentrations in different crop species were investigated.

4. Emneord, norske

1. Handelsgjødsel.
2. Råstoffer.
3. Avling
4. Næringsinnhold og opptak

4. Emneord, engelske

1. Commercial fertilizers
2. Raw materials
3. Crop yield
4. Mineral concentr. and uptake

Prosjektleder:

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Annual Research Report 1993

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Effects of different fertilizers and fertilizer materials on crop yield and on mineral content

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Søndre Østfold, Solør-Odal, Toten, Vestfold, Nedre Telemark, Midt-Agder, Jæren, Ytre Fjordane, Søre Sunnmøre, Rauma og Vestnes, Nesset, Stjørdal & omegn, Midt-Helgeland, Sør-Salten, Lofoten, Vesterålen.

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FOREWORD

The results presented in this report are from experiments conducted under a collaborative research program between the department of Soil and Water Sciences and Norsk Hydro a.s. The report presents the results from nine experimental series conducted under greenhouse and field conditions. Most of the field experiments are executed by the Agricultural Experimental Stations and the Agricultural Experimental Groups in different regions of the country.

In 1993 following experiments are included in the research program: The effects of different sources of magnesium and sulphur on crop yield and uptake of Mg respectively S; the effects of manganese incorporated in NPK fertilizer; the effects selenium and cobalt incorporated in fertilizer on concentration of these elements in dry matter; the effects of silisium on powdery mildew and crop yield; long term field experiments to evaluate the plant availibility of residual phosphorus and to demonstrate the essentiality of macro- and micronutrients on crop growth and nutrient uptake.

The assistance and cooperation from all the collaborating research institutions and individuals are gratefully acknowledged.

Leif Ruud

SAMMENDRAG AV FORSØK UTFØRT 1993

Rapporten for 1993 omfatter 9 forskjellige forsøksserier som er beskrevet detaljert i hvert sitt kapittel. Et kort sammendrag fra disse forsøksseriene følger nedenfor.

1. Selèn-holdig kalksalpeter ved tilleggsgjødsling av vårhvete

Norsk mathvete har lavere innhold av Se enn ønskelig. Formålet med denne forsøksserien er derfor å undersøke om Se-innholdet i hvete kan økes effektivt ved bruk av Se-holdig kalksalpeter. Som bakgrunn for feltforsøkene ble det først startet opp en karforsøksserie i veksthuset som ble avsluttet i 1991. Inklusiv 1993 som var det 4. forsøksåret, er det utført i alt 23 enkeltfelter i vårhvete.

- Se-innholdet i hvete mangedobles ved tilførsel av Se-holdig kalksalpeter, men utslagene for Se-gjødsling har variert fra felt til felt og fra år til år.

- Bruk av Se-holdig kalksalpeter ved begynnende skyting gir generelt like godt resultat som Se-holdig NPK gitt om våren. Under spesielt tørre vekstforhold kan Se-tilførsel om våren være fordelaktig, mens Se-holdig kalksalpeter ved skyting ofte har gitt best resultat når planteveksten er normal.

- Vanligvis er Se-innholdet i vårhvete økt til ønsket nivå ved bruk av kalksalpeter med 25 mg Se kg^{-1} (25 kg vare pr.daa). Effekten varierer med jordtype og særlig klimaforholdene.

- Et år etter tilførsel av Se i lysimetere inneholdt ikke avrenningsvannet Se. Denne undersøkelsen fortsetter.

høyest ved høyeste pH-nivå.

Feltforsøk:

- På de fleste feltene har graset hatt lavt Co-innhold uten Co-gjødsling. Etter gjødsling økte Co-innholdet i graset i takt med Co-innholdet i gjødsla på alle feltene.

- I 1992 ble Co-innholdet i graset noe høyere ved laveste pH-nivået i jorda, men i 1993 gikk virkningen av pH i begge retninger avhengig av felt.

- I motsetning til i 1992 var Co-innholdet i graset ikke høyere i 1. slått enn i 2. og 3. slått.

- Graset på feltene i Vesterålen og på Fureneset har hatt lavt Cu-innhold. Økt Cu-innhold i gjødsla og lav pH i jorda har vanligvis gitt økt Cu-innhold i graset på de fleste feltene.

- I forsøkene har koboltholdig Fullgjødsel økt Co-innholdet i graset effektivt, men innholdet i plantene er også knyttet til egenskaper ved jorda.

3. Effekten av kobolt-holdig kalksalpeter på kobolt-innholdet i raigras.

Kalksalpeter med kobolt testes i karforsøk da det kan være et alternativ til kobolt-holdig Fullgjødsel.

- I raigras dyrket på sandjord økte innholdet og opptaket av Co i avlingen opp til største Co-mengde tilført som Co-holdig kalksalpeter.

- Tilførsel av Co til hver avling førte til jevnere Co-konsentrasjon i tørrstoffet enn samme dose gitt èn gang.

- Fullgjødsel ga sterk avlingsøkning på alle felt i 1993. Når N ble utelatt fra gjødsla, ble både bygg- og grasavlingene redusert ca 50% på alle feltene.

- I bygg ble det sikker avlingsreduksjon bare for N dette året, mens grasavlingene også ble redusert når det ikke ble gjødslet med P, K og S.

- Avlingenes innhold av N og delvis P og S ble redusert når disse næringsstoffene ikke ble tilført. I gras ble også innholdet av K, Mg og B redusert når disse næringsstoffene ble utelatt fra gjødsla. Det ble høyere Mg-innhold i avlingen uten K-gjødsling.

6. Brucitt som Mg-kilde

Brucitt består av 95% $Mg(OH)_2$ og har høyere vannløslighet enn dolomitt. I dette karforsøket blir det vurdert om brucitt er en aktuell Mg-kilde ved produksjon av Fullgjødsel. Dette forsøket har pågått i 2 år.

- Alle Mg-kildene har gitt økt avling av raigras og havre, men økningen har vært betydelig større ved bruk av kieseritt og brucitt enn ved bruk av dolomitt.

- Det var god virkning av kieseritt og brucitt ved begge pH-nivåene og ved separat tilførsel så vel som inngranulert i NP-gjødsla. Virkningen av dolomitt var relativt bedre ved separat tilførsel særlig ved laveste pH-nivå.

- I begge vekstene er innholdet og opptaket av Mg økt ved Mg-gjødsling, og økningen har vært i rekkefølge kieseritt > brucitt > dolomitt.

8. NP-forsøk på sterkt oppgjødslet jord

Denne forsøksserien ble startet i 1989 for å bedømme plantenes behov for P-gjødsling på P-rik jord. Det gjenstår nå 10 fastliggende felt i korn og eng. Resultatene så langt er kort oppsummert nedenfor:

- Det er funnet sikre utslag for P-gjødsling på kornfeltene i 1 eller 2 år av forsøksperioden. Kornfeltene har generelt gitt sikker avlingsøkning for økt N-gjødsling opp til største mengde.

- P-gjødsling påvirket ikke P-opptaket på kornfeltene, mens økt N-gjødsling økte både N- og P-opptaket i avlingen.

- Det har vært positivt utslag for P-gjødsling på alle engfeltene ett eller flere år, og i Jæren FSR og Nesset FSR har det også vært sikre avlingsutslag for P i 2 av forsøksårene. De fleste feltene har gitt avlingsøkning opp til midlere N-mengde (12+8 kg) ett eller flere år av forsøksperioden.

- Både P- og N- gjødsling fremmet P-opptaket i engavlingene. Økt N-gjødsling ga som regel sikker økning i N-opptaket på alle engfeltene.

- Jordprøver som ble uttatt etter 3 års dyrking, viste at P-tilstanden i jorda var redusert på nesten alle felter, men den var lite påvirket av P- eller N-gjødslingen. Nye jordprøver tas ut høsten 1994 etter 6 års dyrking.

SUMMARY AND CONCLUSIONS

In the year 1993, there were in all nine different experimental series which are described separately in detail under each heading. A brief summary of the results from these series is presented below.

1. Effect of Selenium-enriched Calcium Nitrate on the Selenium Concentration in Wheat.

- The concentration and uptake of Se in wheat grain as well as oat and barley grain increased by many times when Se-enriched fertilizers were applied. The total uptake of Se in crop yield varied from site to site being a product of Se concentration in grain and grain yield level.

- 25 mg Se kg^{-1} CN top-dressed at heading was found to encrease Se concentration in grain to desired level.

- Top-dressing of Se through Se-enriched CN was found as effective as basal application of Se through Se-enriched NPK.

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- From all trials with top-dressing of Se-enriched CN it can be concluded that this is an effective method of Se application to increase the Se concentration in wheat grain.

- There has been variation between application methods in Se uptake by wheat. These variations may have been caused by different climate and growing conditions from site to site and among seasons.

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The trials in spring wheat testing Se-enriched CN will be closed after 1994 growing season with exception of the two permanent fields at Ås. However, new trials in winter wheat

- The total uptake of Co followed the same trend as its concentration.

- Leaching losses of Co increased with increased rate of Co application but the losses decreased quite substantially with increased pH in both soils. Similar to Co concentration in plants, the leaching losses of Co in the sand were several fold higher than that in the sandy loam.

- The losses of Cu were also several fold higher in the sand than those in the sandy loam. However, unlike Co the highest losses of Cu were observed at pH 6.5.

Field Experiment

- Last year Co concentration in plants in the control plots was below the level considered adequate for animal fodder at all sites except Ytre Fjordane.

- Similar to the greenhouse experiment, Co concentration in grass increased with increased rate of Co in the fertilizer applied on all sites.

- Co concentration in grass was slightly higher at the lowest soil pH level at all sites in 1992 but at three sites out of six only in 1993. I contrast to 1992 Co concentration was not higher in the first cutting than in the second or third cutting in 1993.

- Concentration of Cu in grass has been below normal level at Fureneset and Vesterålen sites.

- Concentration of Cu in grass has been slightly higher in the treatments with the highest Cu rate applied and at the lowest soil pH level.

- S application resulted in a strong reduction in concentration of nitrate in dry matter of ryegrass and a higher uptake of Kjeldahl N in crop yield.

- Ryegrass yield and S uptake were higher when kieserite and gypsum were applied incorporated in fertilizer compared to separate application. The opposite was the case concerning elementary S.

- In some cases CN resulted in higher crop yield than CN^{18}.

5. Response of Crops to Macro- and Micronutrients in Permanent Fields located in some District of Norway.

- High response in crop yield to applied complete fertilizer on all sites. Big yield reduction in the absence of N on all sites and on average the yield reduction was about 50% in barley as well as grass.

- No significantly response to other nutrient except N in barley this year but the grass yields were also significantly reduced in absence of P, K and S. Absence of K as well as S resulted in yield reductions both at Vågønes and Særheim sites.

- The concentration of N and partly P and S was lower when these nutrients were missing from the fertilizer applied. In the grass fields Mg concentration was lower without Mg fertilization and higher without K fertilization. The concentration of K and B in grass was also reduced without application of these nutrients.

- Fertilizer mixed in to the soil resulted in the highest concentration and uptake of Mn in total crop yield but band placement resulted in the highest grain yield.

8. Phosphorus supplying Capacity of previously heavily Fertilized Soils at increasing Rate of N Application.

- Significant respons to P application in grain crops has been found at all sites, but only for one or two years of the research period. Generally, N rates up to highest level have resulted in significant increase in grain yield at all sites.

- P uptake was not affected by P application in grain crops, but higher rates of N resulted in increased N uptake as well as P uptake.

- Positive response to P application has been observed in grasses at most of the sites and the response has been significant at Nesset and Jæren sites for two years. Generally, there has been positive response to the medium N rate at most of the sites, but at some sites for some years no response to increased N rates has been found.

- Mostly, uptake of P in grasses was increased by P fertilizing and it was also positively influenced by higher N rates. Uptake of N in grasses increased significantly by higher N rates at all sites with only few exceptions.

1. EFFECT OF SELENIUM-ENRICHED CALCIUM NITRATE ON THE SELENIUM CONCENTRATION IN WHEAT.

Selenium (Se) concentration in wheat grown under greenhouse conditions increased in proportion to the rate of Se through Se-enriched calcium nitrate (CN). It was therefore thought desirable to test these results under field conditions. A field study, using some of the treatments from the greenhouse study, was started in 1990 at four sites with different soil types located in the cereal growing areas of southern Norway. One more site was added to this study in 1991, and in 1992 trials was further extended to two more sites in the central part of Norway.

The field experiment in 1993 were laid out at the same sites as in 1992 i.e. Ås and Øsaker Research Stations of Department of Soil and Water Sciences, the Agricultural Experimental Stations Apelsvoll and Kvithamar, the Research Station of the Norwegian Grain Cooperation at Staur and a farmer's field in the two Agricultural Experimental Groups in Vestfold and Stjørdal. At Ås two fields are permanent with a rotation of wheat and oat.

Some selected chemical properties of the soils from Ås, Apelsvoll and Kvithamar are presented in table 1.1. The content of Se in these soils is in the usual low range for soils in the nordic countries.

Table 1.1. Some chemical properties of the soils collected from different sites.

Site	pH (H_2O)	Se mg/kg	P-Al	K-Al	Mg-Al
			---------mg/100 g	-----	-----
Ås	5.7	0.29	6.4	7.4	5.2
Apelsvoll	5.8	0.27	6.3	5.7	8.3
Kvithamar	6.2	0.44	21.0	5.4	14.o

Crop yield

Similar to the previous years the grain yield of wheat (Table 1.2) was not significantly affected by application of Se-enriched CN or NPK with exception of the field at Staur. The low level of grain yields at Ås are caused by dry conditions in the first part of the growing season. From july the weather was cold and rainy and the grain ripening was delied all over the country.

Table 1.2. Dry matter grain yield as affected by Se-enriched fertilizer, kg/daa.

Experimental site		Treatment a	b	c	d
Ås II	(wheat)	278a	250a	259a	271a
Øsaker	"	346a	343a	350a	353a
Apelsvoll	"	353a	358a	362a	356a
Staur	"	586a	597a	602a	572b
Kvithamar	"	306a	308a	304a	293a
Stjørdal	"	403a	402a	388a	410a
Ås I	(oat)	410a	403a	394a	412a
Vestfold	(barley)	599a	588a	575a	622a

Means followed by the same letter in the same row are not significantly different at P = 0.05.

Selenium Concentration and Uptake

Concentration of Se (Table 1.3 and fig. 1.1) increased progressively with increased rates of the Se-enriched CN application on all sites, showing a trend similar to that observed in the previous seasons. One exception was Stjørdal site where the concentration of Se in the control plot was relatively high in contrary to most of the other sites where the values were much below the Se level considered adequate for wheat grain (0.1-0.15 mg kg $^{-1}$) used for human consumption.

Table 1.3. Effect of Se-enriched CN on Se concentration (mg/kg) in cereals.

Exp. site		Treatment a	b	c	d
Ås II	(wheat)	0.014	0.130	0.290	0.320
Øsaker	"	0.048	0.320	0.930	0.270
Apelsvoll	"	0.007	0.054	0.110	0.068
Staur	"	0.005	0.093	0.220	0.160
Kvithamar	"	0.011	0.170	0.380	0.160
Stjørdal	"	0.170	0.140	0.460	0.430
Ås I	(oat)	0.016	0.180	0.520	0.330
Vestfold	(barley)	0.023	0.170	0.370	0.099

The effect of Se-enriched CN was generally as good as in the previous seasons. On all sites except Apelsvoll site 25 mg Se kg^{-1} CN was found to be enough to increase the Se concentration to the desired level. Generally application of Se-enriched NPK increased the Se concentration as much as application of Se-enriched CN. Se enriched NPK was more effective at Ås and Stjørdal sites probably because of special conditions concerning climate and soil. At Ås sites extremely dry conditions during first part of the growth period led to reduced vigour of the plants when CN was top-dressed.

The total uptake of Se was dependent on crop yield level but it was increased with increased rates of Se in the same way as for Se concentration (Fig. 1.2). Generally, it was about the same whether Se was applied as basal application through NPK or as top-dressing through CN with minor exceptions of Ås and Stjørdal sites. Why uptake of Se was higher with basal applied Se-enriched NPK than with top-dressed Se-enriched CN on these two sites is difficult to explain. It can be tied to climate and crop conditions at application time for CN.

No connection between total uptake of Se by plants and different soil textures was observed this year as in last year but in contrast to 1990 and 91 cropping seasons. It is reported that clay content of soil often has a negative relationship to Se uptake in plant.

Conclusions.

- The concentration and uptake of Se in wheat grain as well as oat and barley grain increased by many times when Se-enriched fertilizers were applied. The total uptake of Se in crop yield varied from site to site being a product of Se concentration in grain and grain yield level.

- 25 mg Se kg^{-1} CN top-dressed at heading was found to encrease Se concentration in grain to desired level.

- Top-dressing of Se through Se-enriched CN was found as effective as basal application of Se through Se-enriched NPK.

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- From all trials with top-dressing of Se-enriched CN it can be concluded that this is an effective method of Se application to increase the Se concentration in wheat grain.

- There has been variation between application methods in Se uptake by wheat. These variations may have been caused by different climate and growing conditions from site to site and among seasons.

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- The trials in spring wheat testing Se-enriched CN will be closed after 1994 growing season with exception of the two permanent fields at Ås. However, new trials in winter wheat are started up in 1994 to find the best fertilizing strategi for increasing Se content in this crop. Last summer investigations on leaching losses of Se through a lysimeter study were started up. No Se was found in leaching water by analyzing.

Table 2.1. Some chemical properties of the soils used.

Soil	pH	Org.C	Mn	Fe	Co	Cu	P-Al	Ca-Al
		%	-----	mg kg^{-1}	-----		mg 100	g^{-1}
Sand	6.2	3.4	0.004	0.11	0.05	1.2	31	18
Sandy loam	5.9	4.6	0.01	1.43	0.03	1.4	11	8.9

Greenhouse Experiment

Treatments

The treatments used in 1992 and 1993 were slightly different from those used in 1991 and were as follows:

a. NPK 15-4-12 without Co but with 0.09% Cu
b. NPK 15-4-12 w/ 0.014% Co through $CoSO_4$ +0.09% Cu
c. NPK 15-4-12 w/ 0.014% Co through $CoSO_4$ + 0.3% Cu
d. NPK 15-4-12 w/ 0.03% Co through $CoSO_4$ + 0.09% Cu
e. As treat. a + 0.014 % Co added separately through $CoSO_4$
f. As treat. a + 0.06 % Co added separately through $CoSO_4$
g. As treat. a + 0.1% Co added separately through $CoSO_4$

N-level: 15 kg N daa^{-1} through NPK 15-4-12 with and without Co

pH levels: 5.0, 5.7 and 6.5. pH 7.0 for treat.f and g only

For treatments f and g an additional pH level of 7.0 was included in 1992 in order to assess the effect of high pH and higher levels of Co application. Soil pH has been adjusted to above mentioned values by adding lime or H_2SO_4 as per requirement. The NPK fertilizers with or without Co are thoroughly mixed with 6.67 L of soil. A solution mixture containing Mg, Fe, Mn, B, and Mo are added to each pot. All the treatments were replicated three times.

Ryegrass seed at the rate of 0.9 g was sown in each pot and the pots were watered immediately after sowing. In order to simulate the episodes of rain, additional water was given to

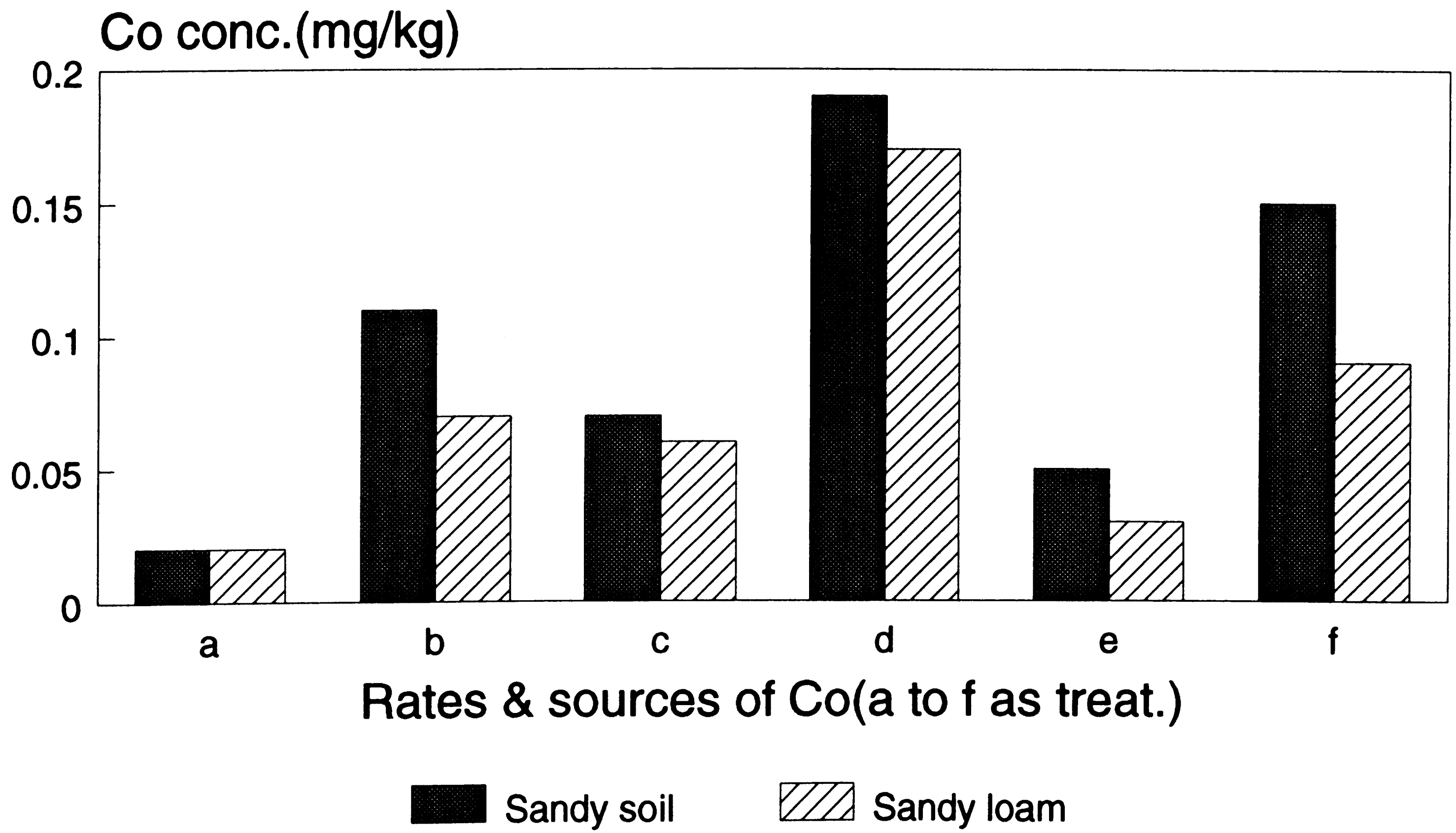


Fig.2.1 Cobalt conc. in ryegrass as affected by the Co-enriched NPK fertilizer(Mean of all pH levels)

from 0.06 to 0.1% of the fertilizer applied (treatments f and g at pH 7.0). The effect of pH was quite consistent in both soils (Fig. 2.2).

Cobalt concentration in ryegrass was decreased when Cu rate was increased from 0.09 to 0.3% in the fertilizer applied (treatment b and c, table 2.3). But the concentration of Cu in ryegrass was little changed by increasing rate of its application (Table 2.4) and either it was not affected by soil type.

Table 2.4. Copper concentration in ryegrass, mg kg^{-1}, grown at different pH levels and in different soils as affected by Co and Cu-enriched NPK.

Treatment	pH levels			
	5.0	5.7	6.5	7,0
		Sand		
a	4.0	3.6	3.5	
b	4.3	3.8	3.4	
c	4.1	2.8	3.7	
d	4.0	3.3	3.6	
e	3.3	3.7	3.6	
f	4.1	3.1	3.3	3.0
g				2.9
		Sandy loam		
a	3.0	4.4	3.7	
b	3.1	3.0	4.5	
c	3.7	2.4	4.6	
d	3.1	3.4	4.0	
e	3.3	3.3	4.0	
f	3.6	2.3	3.4	2.8
g				2.4

The lower concentration of Co in the sandy loam as compared to the sand may have been caused by higher contents of Mn, Fe, and organic matter in the former soil (Table 2.1). This soil constitutens are known to adsorb Co and thereby making it less available to plants. As stated above, the dry matter yield of ryegrass was not affected by Co application and hence, the total uptake of Co (Table 2.5), being a product of the dry matter and Co concentration, followed the same trend as its concentration.

Table 2.5. Effect of Co-enriched NPK on Co uptake by ryegrass, ug/pot, grown at different pH levels and in different soils.

Treatment	pH levels 5.0	5.7	6.5	7.0
		Sand		
a	3.12	1.39	0.94	
b	16.10	3.97	4.26	
c	9.51	3.57	2.95	
d	23.92	11.38	8.74	
e	7.21	2.98	1.47	
f	21.20	9.43	7.29	7.90
g				13.25
		Sandy loam		
a	1.91	1.53	1.39	
b	8.24	5.86	3.88	
c	6.24	4.70	3.14	
d	18.17	13.19	10.03	
e	3.03	2.15	2.44	
f	10.87	5.73	5.74	6.87
g				11.35

Leaching losses

Leaching water from the experiment in 1993 is not analysed, and the results from 1991 and 1992 have been reported earlier. A short summary of this is given below.

Leaching of Co increased with increased rate of Co and decreased quite substantially with increased pH in both soils. Leaching losses of Co were several fold higher in sand than in the sandy loam and the losses were generally very low at pH 6.5 in both soils. The leaching losses of Co were little affected by Cu application.

The losses of Cu were also several fold higher in the sand than in the sandy loam. However, unlike Co the highest losses of Cu were observed at pH 6.5. This may perhaps be due to higher complexing ability of Cu with organic matter.

Treatments

The treatments used for the two field experiments at Særheim in 1992 were as follows:

a. NPK 15-4-12 without Co but with 0.09 % Cu
b. NPK 15-4-12 with 0.014 % Co through $CoSO_4$ +0.09 % Cu
c. NPK 15-4-12 with 0.012 % Co through $CoSO_4$ +0.25 % Cu
d. NPK 15-4-12 with 0.030 % Co through $CoSO_4$ +0.09 % Cu

The treatments used for the field experiments at the other locations in 1992 and at all locations in 93 were as follows:

a. NPK 15-4-12 without Co but with 0.23 % Cu
b. NPK 15-4-12 with 0.022 % Co through $CoSO_4$ + 0.09 % Cu
c. NPK 15-4-12 with 0.012 % Co through $CoSO_4$ + 0.25 % Cu
d. NPK 15-4-12 with 0.044 % Co through $CoSO_4$ + 0.09 % Cu

pH-levels: 5.0 and 6.0

Location 7.Vesterålen had only one pH-level (7.6) but three more treatments were added:

e. NPK 15-4-12 w.out Co, with 0.23% Cu + 0.06% Co sep. i $CoSO_4$
f. NPK 15-4-12 w.out Co, with 0.23% Cu + 0.09% Co sep. i $CoSO_4$
g. NPK 15-4-12 w.out Co, with 0.23% Cu + 4 g Co daa^{-1} (foliar fertilizing)

N-level: 12 kg N daa^{-1} through NPK 15-4-12 with and without Co.

The experiments were laid out in a randomized block design with three replicates. The plot size was 12 m^2 with a harvested area of 6 m^2. Nitrogen was applied at the rate of 12 kg daa^{-1} through NPK 15-4-12 fertilizers with and without Co which also supplied 3.2 and 9.6 kg daa^{-1} P and K, respectively. Cobalt in the fertilizer was incorporated during the manufacture process. The treatment fertilizers were applied only in spring on all locations but additional fertilizer was applied to 2. and 3. crop yields.

Soil pH was adjusted to about 5.0 and 6.0 using H_2SO_4 or lime as per requirement. Ryegrass was grown at Særheim sites and meadow grass (mostly timothy and meadow fescue) were test

Cobalt and Copper concentrations

Similar to the greenhouse experiment, Co concentration in grasses increased with increased rate of Co in the fertilizer applied at all sites (Table 2.9). At all sites except the two locations at Y. Fjordane, the concentration of Co in plants in the control plots generally was below the level considered adequate for animal fodder (0.11 - 0.15 mg kg^{-1}). The smallest Co quantity added (treatment c) seems to give sufficient concentration of Co in the plants in all cuttings at some of the sites, but at the two locations 2.Særheim and 7.Vesterålen higher quantities of Co must be added. Foliar spraying of Co at location 7.Vesterålen was effectiv enough only in 1. cutting. This year there was a trend showing higher content of Co in crop yield at the lowest pH level only at the three locations 2.Særheim, Fureneset and 5. Y.Fjordane. The concentration of Co was not declining in 2. or 3. cuttings this year.The effect of Cu on Co uptake could not be evaluated because both Co and Cu applied varied in the treatments.

Cu concentration in grass was below normal level (5 - 15 mg kg^{-1}) at Fureneset and the two locations in Vesterålen. (Table 2.10). At the two locations at Særheim Cu concentration was rather low in 1.cutting but being somewhat higher in 2. and 3. cutting. Generally, Cu concentration in grass was slightly higher in the treatments with the highest Cu rate applied (a and c) and at the lowest soil pH level compared with the highest pH level.

Table 2.10. Cu concentration in grass as affected by Co- and Cu-enriched NPK, mg kg^{-1}.

Treatment	1.cutting pH 5.0	1.cutting pH 6.0	2.cutting pH 5.0	2.cutting pH 6.0	3.cutting pH 5.0	3.cutting pH 6.0
	S132 01 SFL SÆRHEIM					
a	4.4	4.2	5.5	4.6	5.3	5.0
b	4.3	4.1	4.9	4.5	5.2	5.3
c	4.4	4.1	5.5	4.8	6.0	5.4
d	4.3	4.0	4.7	4.4	5.1	4.9
	S132 02 SFL SÆRHEIM					
a	4.1	4.2	5.9	5.9	5.7	5.3
b	5.5	4.0	6.2	6.0	7.0	5.9
c	4.4	4.3	6.6	6.5	6.2	5.8
d	4.4	3.9	6.6	6.2	5.5	5.7
	S132 03 SFL FURENESET					
a	3.0	1.7	4.5	2.0		
b	2.0	1.3	2.2	1.6		
c	2.6	1.8	2.9	2.3		
d	2.4	1.3	2.1	1.7		
	S132 04 YTRE FJORDANE FSR					
a	6.7	6.2	6.8	6.0		
b	7.5	7.2	4.7	6.5		
c	7.2	7.3	6.3	5.9		
d	6.0	5.9	6.3	4.9		
	S132 05 YTRE FJORDANE FSR					
a	9.4	7.3	8.5	6.8		
b	9.3	6.8	6.6	6.8		
c	10.3	8.8	9.3	9.1		
d	7.7	6.7	7.4	7.1		
	S132 06 VESTERÅLEN					
a	3.6	2.5	5.1	4.4		
b	2.8	3.2	4.4	4.0		
c	3.9	3.5	5.5	4.6		
d	3.2	2.3	4.1	4.0		
	S132 07 Vesterålen (pH 7.6)					
a	2.4		3.4			
b	2.2		1.3			
c	2.0		2.0			
d	1.5		1.4			
e	1.9		1.6			
f	1.7		1.7			
g	2.1		1.8			

- The losses of Cu were also several fold higher in the sand than those in the sandy loam. However, unlike Co the highest losses of Cu were observed at pH 6.5.

Field Experiment

- Last year Co concentration in plants in the control plots was below the level considered adequate for animal fodder at all sites except Y.Fjordane.

- Similar to the greenhouse experiment, Co concentration in grass increased with increased rate of Co in the fertilizer applied on all sites.

- Co concentration in grass was slightly higher at the lowest soil pH level at all sites in 1992 but at three sites out of six only in 1993. I contrast to 1992 Co concentration was not higher in the first cutting than in the second or third cutting in 1993.

- Concentration of Cu in grass has been below normal level at Fureneset and Vesterålen sites.

- Concentration of Cu in grass has been slightly higher in the treatments with the highest Cu rate applied and at the lowest soil pH level.

- The results from these studies show that Co-enriched NPK is an effective source for increasing the Co concentration in grass to a desired level but the concentration is also controlled by soil properties.

ryegrass NPK 15-4-12 with Mg, S and Cu equivalent to 20 kg N/daa supplied by 1.5 kg P/daa and a solution mixture containing Fe, Mn, B and Mo was added to each pot. The pots were watered with deionized water immediately after sowing and at a regular time interval through the growth period. Ryegrass was cut 3 times during the experiment and the treatments were done after 1. and 2. cuts. Potassium-chloride equivalent to 12 kg K/daa was also added all pots after 1. and 2. cuts to supply enough K to the crops.

Crop yield

Co is not proved to be an essential nutrient to plants, but it is necessary for microbiological N-fixation from air. In this experiment dry matter yield of ryegrass was significantly increased by CN with cobalt compared with CN without cobalt. The yield of ryegrass was also significantly influenced by soil pH (Table 3.2 and fig. 3.1).

Table 3.2. Total dry matter yield of ryegrass as affected by Co-enriched CN applied at two pH-levels, g/pot.

Treatm.	pH 6.0	pH 7.0	Mean
a.	54.4	52.9	53.6b
b.	52.9	53.4	53.1b
c.	56.0	53.8	54.9a
d.	55.9	54.2	55.1a
Mean	54.8a	53.6b	

Means with the same letter in the same column are not significantly different at P=0.05

Cobalt concentration and uptake

Concentration of Co in ryegrass was increased very distinct by Co-enriched CN (Table 3.3 and fig.3.2). One application of Co-enriched CN (treatm. b) resulted in residual effect at 3. cut of ryegrass, but half quantity of Co after 1. and 2. cut (treatm. d) resulted in more even Co concentration in each crop. This indicate that Co was partly absorbed by the soil

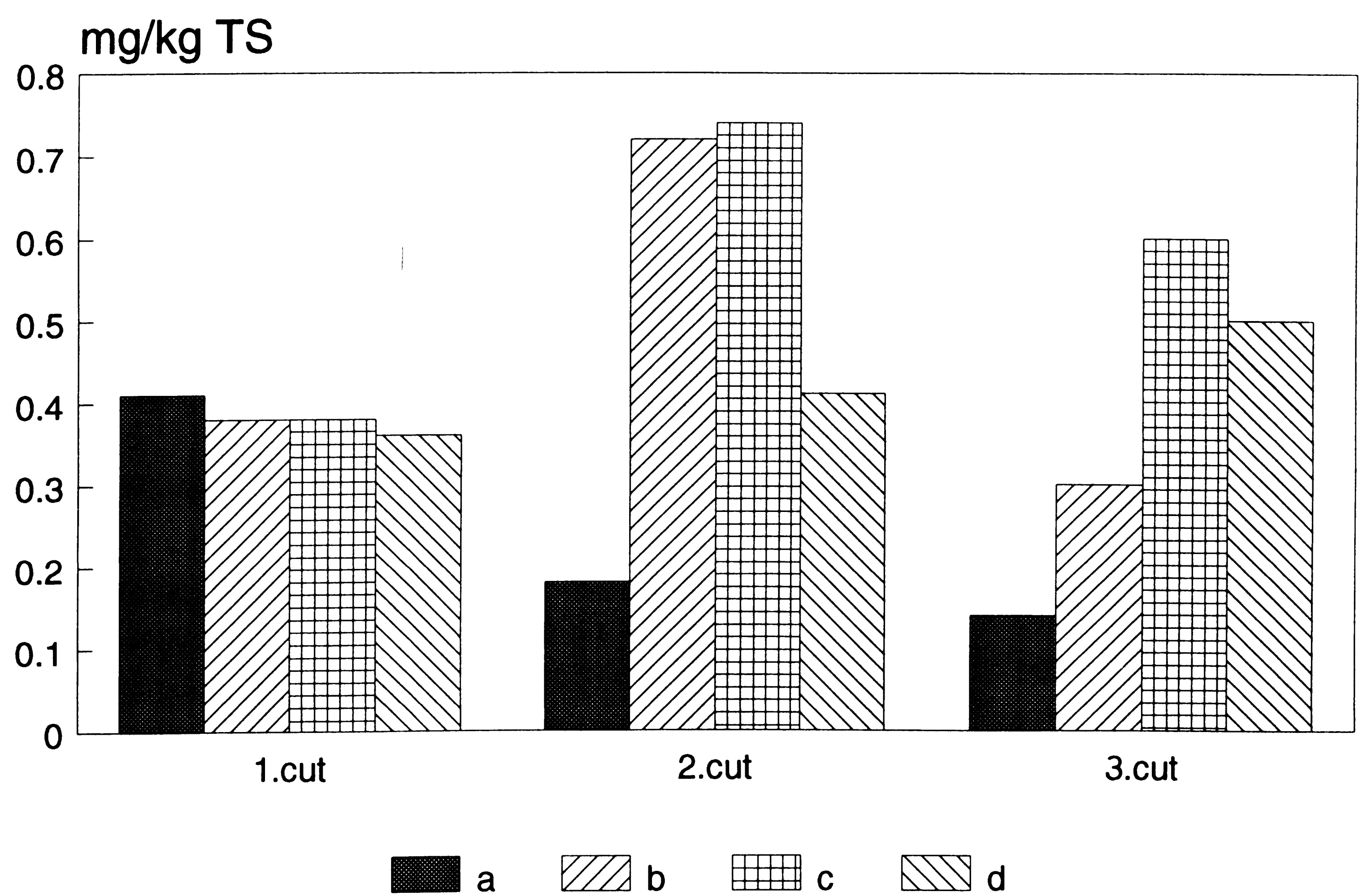


Fig. 3.2 Concentration of Co in ryegrass as effected by Co-enriched CN (Mean of 2 pH levels).

and thereby making it less available to plants. Concentration of Co increased by double rates of Co-enriched CN (treatm. c).

Concentration of Co in ryegrass was markedly decreased by increased pH level, but still a distinct increase in concentration occurred. The relations between the treatments were the same at both pH levels.

Table 3.3. Effect of Co-enriched CN on Co concentration in ryegrass at two pH levels, mg kg^{-1}.

Treat ment	1. cut pH 6	1. cut pH 7	2. cut pH 6	2. cut pH 7	3. cut pH 6	3. cut pH 7	Mean pH 6	Mean pH 7
a.	0.44	0.38	0.24	0.13	0.13	0.15	0.28	0.21
b.	0.39	0.36	0.89	0.55	0.27	0.34	0.52	0.43
c.	0.43	0.34	0.92	0.56	0.66	0.54	0.66	0.49
d.	0.37	0.34	0.57	0.25	0.62	0.38	0.51	0.32
Mean	0.41	0.36	0.65	0.37	0.42	0.36	0.50	0.36

The uptake of Co in ryegrass followed the same trend as the concentration because of small differanses in crop yield between treatments (Table 3.4 and fig. 3.3).

Table 3.4. Effect of Co-enriched CN on Co uptake by ryegrass grown at two pH levels, µg/pot.

Treat ment	1. cut pH 6	1. cut pH 7	2. cut pH 6	2. cut pH 7	3. cut pH 6	3. cut pH 7	Total pH 6	Total pH 7
a.	9.11	6.16	4.11	2.70	2.06	2.37	15.28	11.23
b.	7.73	5.43	15.88	12.38	4.13	5.40	27.74	23.21
c.	8.85	5.51	17.32	12.11	10.86	8.66	37.03	26.29
d.	7.43	5.44	10.70	5.31	10.66	6.41	28.79	17.16
Mean	8.28	5.63	12.00	8.13	6.93	5.71	27.21	19.47

4. EFFECT OF SULPHUR-SOURCES INCORPORATED IN CALSIUM NITRATE TO RYEGRASS AND BARLEY.

In the last years the demand for sulphur in fertilizers has been increasing by many reasons. This has been met by increasing the sulphur content in NPK fertilizers and by introduce sulphur in ammonium-nitrate fertilizer. It is also of great interest to add sulphur to Calsium Nitrate (CN) because CN is very much made use of as nitrogen fertilizer.

In the production of CN with sulphur incorporated different sulphur-sources can be used. Therefore, pot trials were laid out in 1993 to test the effect of topical sulphur-sources when they are incorporated in CN. A sandy soil was used for the first experiment started up in climate chamber and the same soil mixed up with 20% volumes of sphagnum peat was used for the second experiment in greenhouse. Some selected properties of the sand and the peat are presented in table 4.1.

Table 4.1. Selected properties of the soils used

	*	P-AL	K-AL	Mg-AL	Ca-AL	Tot-S	Mn	B
		- - -	mg/100	gram	- - -	- - -	mg/kg	- - -
Sand	0.3	2.3	<1.0	1.1	8.4	8.4	0.2	0.1
Peat	93.6	1.1	5.6	38	62	780	32.7	

* loss on ignition

EXPERIMENT I

This experiment was started up in climate chamber in march and moved to greenhouse later on in the spring. The sandy soil used in the test was not limed because pH was measured to 5.6. Ryegrass respectively barley as test plants were grown in pots of 3 litres.

Ryegrass was harvested only once and barley was harvested as green crop before heading. Dry matter yield in ryegrass as well as barley was increased significantly by nearly all sulphur treatments (Table 4.2). The yield response of ryegrass was significantly higher by applying Calsium Nitrate + kieserite separate compared to when elementary S was applied separate and when the S-sources were incorporated in the fertilizer. CN + kieserite resulted also in significant higher crop yield than all other treatments in barley.

Table 4.2. Effect of different S sources on dry matter yield of ryegrass and barley, g/pot.

Treatm.	Ryegrass	Barley
a. CN without S	1.1d	1.1d
b. CN[18] w/gypsum incorp.	2.8bc	2.2bc
c. " w/elem. S incorp.	2.6c	2.3bc
d. " w/kieserite incorp.	2.8bc	1.8bcd
e. " + gypsum separate	3.8ab	2.7b
f. " + elem. S separate	2.2c	1.4cd
g. " + kieserite separate	3.6ab	2.3b
h. CN + kieserite separate	4.2a	3.6a

Concentration and uptake of N and S.

The recovery % of N as well as S was small because of the bad growing conditions. Application of sulphur has increased concentration and uptake of S and resulted in a more normal content of N in crop yield of ryegrass as well as barley. The highest increase in concentration and uptake of S was obtained by separate application of gypsum. The content of nitrate N was very high in all treatments (Table 4.3).

EXPERIMENT II

In this greenhouse experiment ryegrass and barley as test plants were grown in pots of 6.7 litres. The sandy soil mixed with 20% volumes of peat was added 8.0 gram $CaCO_3$ to each pot getting a pH value of about 6.0.

Part 1:

Test fertilizers mixed into the soil before sowing of ryegrass

Treatments:

a. Calsium Nitrate without sulphur
b. CN^{18} with S as kieserite incorporated
c. CN^{18} with S as gypsum incorporated
d. CN^{18} with S as elementary S incorporated
e. CN^{18} + S in kieserite separate
f. CN^{18} + S in gypsum separate
g. CN^{18} + S in elementary S separate

Quantity of N and S added were corresponding to 18.8 and 3 kg/daa, respectively.

All treatments were replicated three times. In addition to the test fertilizer P as $Ca(H_2PO_4)$ and K as KCl corresponding to 6 and 21 kg/daa, respectively, as well as a micronutrient mixture containing Fe, Mn, Cu, Zn, B and Mo were added to each pot. All treatments without kieserite were added Mg as $MgCl_2$ to supply with equivalent quantity of Mg. All nutrients were thoroughly mixed into the soil before sowing of ryegrass.

Ryegrass was harvested 4 times during the growing season. Calsium Nitrate and KCl corresponding to 12 kg/daa of N and K were top dressed after 1. and 2. cut and corresponding to 6 kg/daa of N and K after 3. cut.

Crop yield.

The response to sulphur, irrespective of the source, was highly significant (Table 4.4). However, ryegrass yield was

S application. The effect of S was better when kieserite and gypsum were applied compared to elementary S. The effect of kieserite was little influenced by the application method but gypsum and elementary S responded somewhat better respectively incorporated in fertilizer and applied separatly.

Part 2:

Test fertilizers applied on dry soil surface one week after emergence of seedlings.

Test plants: 1) Ryegrass. 2) Barley

Treatments:

a. Calsium Nitrate without sulphur
b. Calsium Nitrate + S in kieserite separate
c. CN^{18} + S in kieserite separate
d. CN^{18} with S as kieserite incorporated
e. CN^{18} with S as gypsum incorporated
f. CN^{18} with S as elementary S incorporated

Quantity of N and S added were corresponding to 18.8 and 3 kg/daa, respectively.

All treatments were replicated three times. P as $Ca(H_2PO_4)$ and K as KCl corresponding to 4.5 and 15 kg/daa, respectively, as well as a micronutrient mixture as in part 1 were added and thoroughly mixed into each pot before sowing. NPK 17-5-13 with 1.2% Mg and 1.6% S corresponding to 50 kg/daa was also added to secure some Mg and S before the test fertilizers were added. Mg as $MgCl_2$ was added in all treatments without kieserite to supply with equivalent quantity of Mg.

Ryegrass being harvested 4 times was top dressed with Calsium Nitrate and KCl as in part 1 after 1., 2. and 3. cut. Barley being harvested at ripening was not top dressed.

Concentration and uptake of N and S.

As in part 1 all S treatments resulted in higher concentration and uptake of S as well as lower content of N and nitrate N in crop yields of ryegrass and barley (Tables 4.8 and 4.9). There was little difference between the S treatments, but concentration and uptake of S was somewhat lesser by application of elementary S in ryegrass. Kieserite responded best on concentration and uptake of S when it was incorporated in CN.

Table 4.8. Effect of sources of S on content (%) and uptake (mg/pot) of Kjeldahl N, nitrate N and total S in ryegrass. Average and sum of 4 harvests for the content and uptake, respectively.

	Kjeldahl N		Nitrate N		Total S	
	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
a.	2.22	902	0.050	20.2	0.07	29
b.	1.35	1129	0.011	9.4	0.12	96
c.	1.44	1148	0.011	8.5	0.13	101
d.	1.39	1180	0.011	9.0	0.13	112
e.	1.36	1074	0.011	8.4	0.13	105
f.	1.44	1057	0.011	8.3	0.11	81

Table 4.9. Effect of sources of S on content (%) and uptake (mg/pot) of Kjeldahl N, nitrate N and total S in grain and straw of barley.

	Kjeldahl N		Nitrate N		Total S	
	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
			Grain			
a.	1.87	461	0.01	2.7	0.08	19
b.	1.88	623	0.01	3.6	0.13	43
c.	1.55	529	0.01	3.7	0.13	45
d.	1.70	557	<0.01	3.6	0.14	46
e.	1.56	527	0.01	3.7	0.14	48
f.	1.57	560	<0.01	3.9	0.14	51
			Straw			
a.	0.74	157	0.01	2.3	0.07	14
b.	0.48	125	<0.01	2.8	0.12	31
c.	0.48	132	<0.01	2.9	0.12	32
d.	0.53	145	<0.01	2.9	0.14	38
e.	0.50	141	0.01	3.0	0.13	36
f.	0.51	140	0.01	2.9	0.09	25

Conclusions

- The yield of ryegrass as well as barley increased significantly with S application irrespective of its source but in ryegrass the increase was significantly higher by application of kieserite and gypsum than by application of elementary S.

- The concentration and uptake of S increased very much by all S sources applicated and the rate of increase was in the order kieserite = gypsum > elementary S.

- S application resulted in a strong reduction in concentration of nitrate in dry matter of ryegrass and a higher uptake of Kjeldahl N in crop yield.

- Ryegrass yield and S uptake were higher when kieserite and gypsum were applied incorporated in fertilizer compared to separate application. The opposite was the case concerning elementary S.

- In some cases CN resulted in higher crop yield than CN^{18}.

Kvithamar and the content of B in soils from Solør-Odal and Ås seems to be on the lower side.

The trials were continued at all sites in 1993 except at the Agricultural Experimental Group of Buskerud. The experimental sites can be find in table 5.2. The treatments used in the experiments in 1993 were the same as used in the previous years and are presented below:

Treatments

A) Complete fert. with N, P, K, Mg, S, and B
B) As A) but without N
C) As A) but without P
D) As A) but without K
E) As A) but without Mg
F) As A) but without S
G) As A) but without B
H) As A) but without Mg, S, and B
I) Control

The amounts of nutrients added in each treatment through these fertilizers are given in table 5.1. These amounts are based at the rate applied for cereals of 10 kg N daa^{-1} through different fertilizers. Fertilizer rate applied for grass was corresponding to 12 kg N daa^{-1} in spring. N and K only were applied after 1.cut.

All the fertilizers were applied as basal dose prior to sowing of cereals or in early spring for grass. The crops grown in 1993 were barley at Ås, Apelsvoll, Solør-Odal, Kvithamar and N. Telemark and grass at Vågønes and Særheim. The treatments at each site were replicated 3 times. The plot size was 24 m^2, with a harvested area of 12 m^2. Grain crops were harvested at maturity and threshed to separate grain and straw but only the reduced in absence of S at Vågønes site and in absence of P and K at Særheim site. At Vågønes site absence of S resulted in reduced yield in 1.cut as well as 2. cut and the need for S was also underlined by the reduced yield when Mg, S and B applied together were missing in the fertilizer scheme. The yield tended te be reduced also in absence of K and this reduction was significant in 2. cut. In addition to effect of P and K at Særheim site yield tended to be lower in absence of S and this yield reduction was significant in 1. cut.

Table 5.2. Response of barley and grass crops to the presence or absence of different nutrients in the fertilizer applied.

Treatm.	Barley, DM grain yield (kg daa^{-1}) Ås	Apelsvoll	Solør-Odal	Kvithamar	N.Telemark
a	300ab	439ab	367a	461a	290ab
b-N	175c	187c	174b	259b	182c
c-P	279b	436ab	369a	439a	298ab
d-K	329a	401b	337a	449a	277b
e-Mg	289ab	438ab	350a	461a	297ab
f-S	261b	445ab	353a	461a	318ab
g-B	304ab	466a	375a	460a	327a
h-Mg,S,B	282b	430ab	375a	434a	303ab
i(contr.)	185c	196c	157b	248b	175c

Treatm.	DM grass yield (kg daa^{-1}) Vågønes			Særheim		
	1.cut	2.cut	Total	1.cut	2.cut	Total
a	764a	223a	987ab	440ab	345a	785a
b-N	407c	74d	481d	323d	42b	365d
c-P	733ab	225a	958ab	329d	378a	708bc
d-K	681ab	184b	866abc	338d	341a	680c
e-Mg	764a	237a	1001a	433abc	332a	765ab
f-S	634b	133c	767c	386c	357a	743ab
g-B	741ab	202ab	943ab	444a	348a	792a
h-Mg,S,B	712ab	142c	855bc	394bc	357a	751ab
i(contr.)	373c	34e	407d	241e	35b	277e

Means with the same letter in the same column are not significantly different at P=0.05

Treat-ment	N	P	K	Mg	S	B
	%					mg kg^{-1}
(Wheat)	Buskerud					
a	2.80	0.43	-	0.14	0.19	<1.0
b-N	2.43	0.43	-	0.15	0.18	<1.0
c-P	2.93	0.45	-	0.15	0.20	<1.0
d-K	2.85	0.42	-	0.15	0.19	<1.0
e-Mg	3.03	0.44	-	0.15	0.20	<1.0
f-S	2.73	0.42	-	0.15	0.19	<1.0
g-B	2.84	0.43	-	0.15	0.18	<1.0
h-Mg,S,& B	3.00	0.44	-	0.15	0.19	<1.0
i(contr.)	2.25	0.43	-	0.15	0.17	<1.0
(Barley)	Solør-Odal					
a	2.00	0.36	-	0.11	0.14	<1.0
b-N	1.58	0.38	-	0.11	0.12	<1.0
c-P	1.94	0.36	-	0.11	0.15	<1.0
d-K	1.96	0.37	-	0.12	0.15	<1.0
e-Mg	1.94	0.36	-	0.11	0.13	<1.0
f-S	1.95	0.36	-	0.11	0.13	<1.0
g-B	1.95	0.35	-	0.11	0.14	<1.0
h-Mg,S & B	1.94	0.37	-	0.11	0.14	<1.0
i(contr.)	1.54	0.38	-	0.11	0.12	<1.0
(Barley)	Kvithamar					
a	1.79	0.46	-	0.11	0.14	<1.0
b-N	1.47	0.40	-	0.11	0.12	<1.0
c-P	1.82	0.44	-	0.12	0.13	<1.0
d-K	1.92	0.45	-	0.11	0.14	<1.0
e-Mg	1.78	0.45	-	0.11	0.14	<1.0
f-S	1.89	0.47	-	0.12	0.14	<1.0
g-B	1.79	0.45	-	0.12	0.14	<1.0
h-Mg,S & B	1.89	0.46	-	0.11	0.15	<1.0
i(contr.)	1.43	0.39	-	0.11	0.12	<1.0
(Oats)	N.Telemark					
a	2.44	0.40	-	0.17	0.21	<1.0
b-N	2.50	0.42	-	0.17	0.14	<1.0
c-P	2.07	0.40	-	0.17	0.21	<1.0
d-K	2.47	0.39	-	0.17	0.18	<1.0
e-Mg	2.36	0.38	-	0.16	0.18	1.6
f-S	2.60	0.39	-	0.17	0.20	<1.0
g-B	2.43	0.38	-	0.16	0.18	<1.0
h-Mg,S & B	2.44	0.39	-	0.17	0.21	<1.0
i(contr.)	2.06	0.45	-	0.18	0.18	<1.0
(Grass, 1.cut)	Vågønes					
a	2.44	0.31	-	0.24	0.22	1.0
b-N	1.08	0.25	-	0.14	0.13	3.2
c-P	2.21	0.29	-	0.24	0.27	1.8
d-K	2.42	0.33	-	0.27	0.23	2.0
e-Mg	2.39	0.33	-	0.22	0.22	2.5
f-S	2.22	0.32	-	0.25	0.15	2.4
g-B	2.42	0.31	-	0.26	0.23	<1.0
h-Mg, S,& B	2.29	0.32	-	0.21	0.15	1.1
i(contr.)	1.24	0.26	-	0.16	0.14	1.2

Treat-ment	N	P	K	Mg	S	B
	%					mg kg^{-1}
(Barley)	Apelsvoll					
a	1.59	0.36	0.43	0.11	0.14	<1.0
b-N	1.37	0.38	0.44	0.10	0.13	<1.0
c-P	1.47	0.32	0.41	0.10	0.13	<1.0
d-K	1.60	0.37	0.44	0.11	0.14	<1.0
e-Mg	1.51	0.36	0.43	0.11	0.13	<1.0
f-S	1.51	0.35	0.42	0.10	0.13	<1.0
g-B	1.50	0.36	0.43	0.10	0.13	<1.0
h-Mg,S,& B	1.53	0.37	0.44	0.11	0.13	<1.0
i(contr.)	1.39	0.39	0.47	0.11	0.14	<1.0
(Barley)	Solør-Odal					
a	1.44	0.35	0.54	0.10	0.12	<1.0
b-N	1.22	0.37	0.51	0.10	0.11	<1.0
c-P	1.49	0.32	0.54	0.10	0.12	<1.0
d-K	1.36	0.35	0.54	0.10	0.12	<1.0
e-Mg	1.41	0.35	0.54	0.10	0.12	<1.0
f-S	1.52	0.34	0.53	0.10	0.12	<1.0
g-B	1.39	0.34	0.53	0.10	0.12	<1.0
h-Mg,S & B	1.42	0.35	0.54	0.10	0.12	<1.0
i(contr.)	1.21	0.36	0.52	0.10	0.11	<1.0
(Barley)	Kvithamar					
a	1.50	0.36	0.45	0.10	0.11	<1.0
b-N	1.07	0.36	0.41	0.11	0.10	<1.0
c-P	1.42	0.34	0.43	0.10	0.11	<1.0
d-K	1.47	0.36	0.44	0.10	0.12	<1.0
e-Mg	1.51	0.38	0.46	0.11	0.12	<1.0
f-S	1.43	0.38	0.46	0.11	0.11	<1.0
g-B	1.56	0.40	0.47	0.11	0.11	<1.0
h-Mg,S & B	1.41	0.36	0.45	0.11	0.11	<1.0
i(contr.)	1.08	0.36	0.43	0.11	0.09	<1.0
(Barley)	N.Telemark					
a	2.00	0.29	0.31	0.12	0.14	<1.0
b-N	1.41	0.36	0.36	0.12	0.11	<1.0
c-P	1.91	0.28	0.32	0.11	0.14	<1.0
d-K	1.99	0.29	0.31	0.12	0.14	<1.0
e-Mg	2.04	0.28	0.32	0.11	0.13	<1.0
f-S	1.96	0.27	0.29	0.11	0.12	<1.0
g-B	1.87	0.27	0.31	0.11	0.12	<1.0
h-Mg,S & B	1.36	0.38	0.38	0.12	0.11	<1.0
i(contr.)	2.00	0.28	0.33	0.11	0.14	<1.0

Conclusions

- High response in crop yield to applied complete fertilizer at all sites. Big yield reduction in the absence of N on all sites and on average the yield reduction was about 50% in barley as well as grass.

- No significantly response to other nutrient except N in barley this year but the grass yields were significantly reduced in absence of P, K and S. Absence of K as well as S resulted in yield reductions both at Vågønes and Særheim sites. Grass crops have responded to S at Vågønes site and to K at Særheim site every year since the fields were laid out.

- The concentration of N and partly P and S was lower when these nutrients were missing from the fertilizer applied. In the grass fields Mg concentration was lower without Mg fertilization and higher without K fertilization. The concentration of K and B in grass was also reduced without application of these nutrients.

mixture containing 3.0 1.6 1.2 0.06 0.05 kg da^{-1} of Fe, Mn, Cu, B and Mo, respectively, were given to each pot. Nitrogen through calsium nitrate and potassium through potassium chloride each at the rate of 12, 12 and 6 kg daa^{-1} were topdressed in ryegrass after 1., 2. and 3. cutting, respectively. The moisture content in the pots was maintained by regular watering with deionized water. Ryegrass was harvested 4 times during the cropping season and oat was harvested at maturity. The dry matter yield of ryegrass and the grain and straw yields of oat were recorded.

Crop Yield

The grain and straw yields of oat were greatly affected by soil pH and by all Mg-sources (Table 6.2). When pH was rised from 5.5 to 6.5 the grain yield were doubled many times but the relative effect of the Mg-sources were little influenced. The grain and straw yields were significant lesser by use of dolomite as Mg-sources than by use of brucite and kieserite. The effect of dolomite applicated separatly was relatively much better than incorporated in NP and at the lowest pH as good as for the two other Mg-sources. The increase in grain yield was higher by use of brucite than by use of kieserite. This difference was significant when the Mg-sources were incorporated in NP.

Table 6.2 Effects of different Mg sources on grain and straw yields of oat, (g/pot).

Treatm.	Grain			Straw		
	pH 5,5	pH 6,5	Mean	pH 5,5	pH 6,5	Mean
a.	0.1	19.3	9.7 e	1.7	22.7	12.2 d
b.	12.3	37.6	25.0 a	11.4	27.4	19.4 a
c.	1.0	26.3	13.6 d	5.0	23.8	14.4 c
d.	4.9	36.1	20.5 c	11.9	27.5	19.7 a
e.	7.5	39.7	23.6 ab	10.5	28.9	19.7 a
f.	7.0	34.0	20.5 c	10.4	25.9	18.1 b
g.	7.7	38.4	23.1 b	10.7	28.8	19.7 a
Mean	5.8 b	33.1 a		8.8 b	26.4 a	

Means with the same letter in the same column are not significantly different at P=0,05

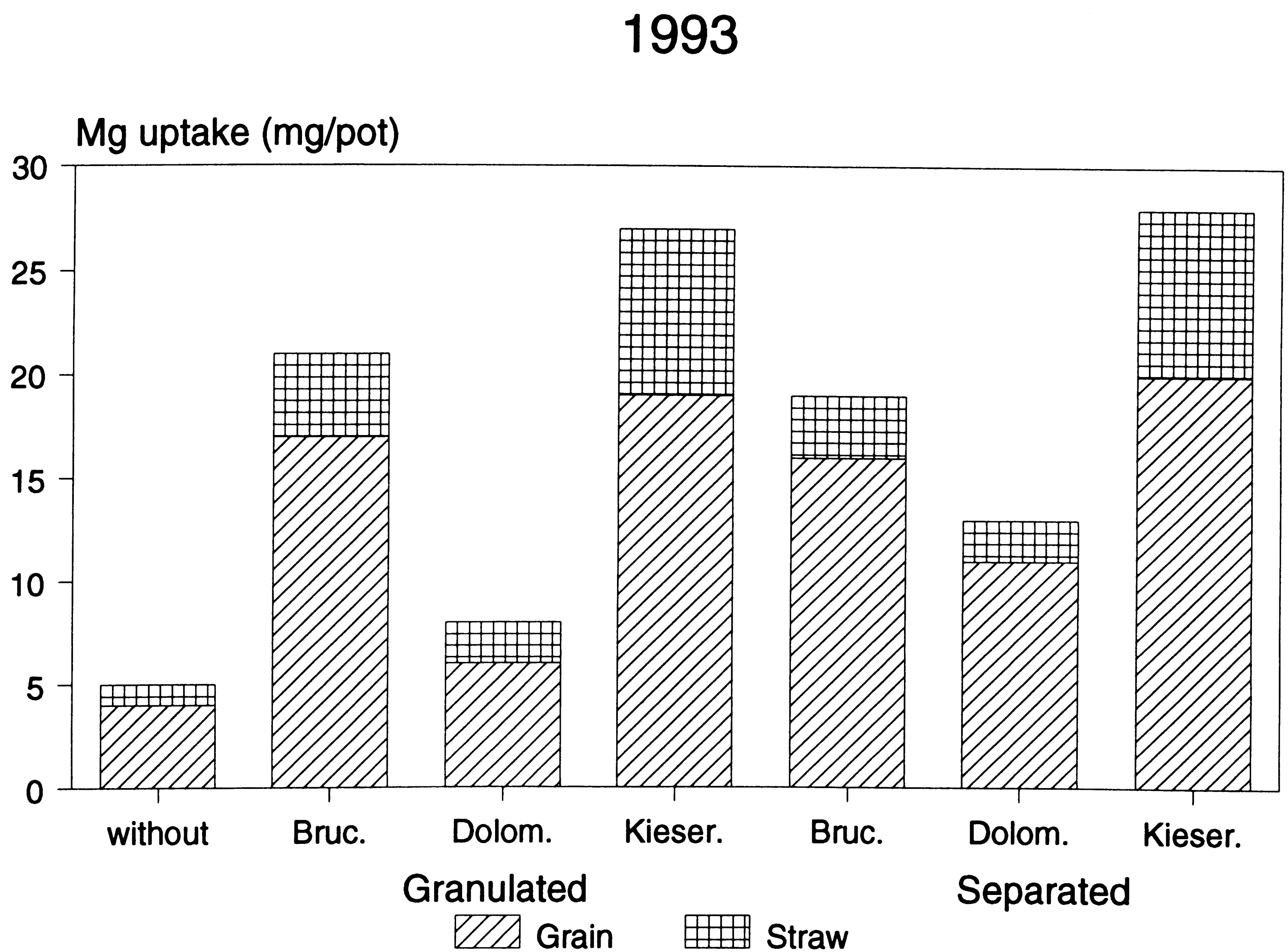


Fig 6.1 Mg uptake in Grain and Straw of Oats

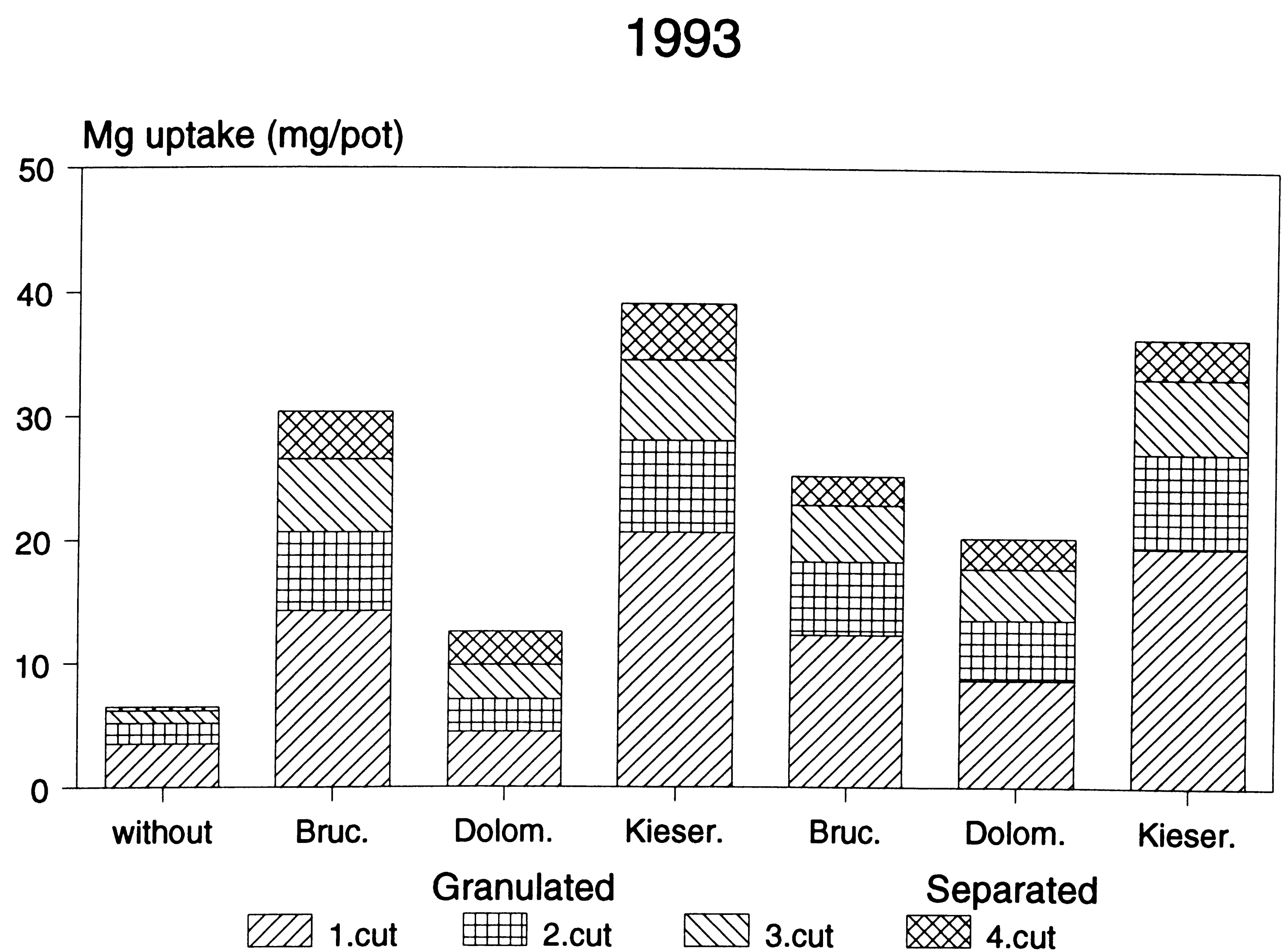


Fig 6.2 Mg uptake in Ryegrass

Conclusions

- The yield of oat as well as ryegrass increased significantly with Mg application irrespective of its source, but the increase was much higher by use of brucite and kieserite than by use of dolomite.

- The relative effect of brucite and kieserite on crop yield was little influenced by soil pH or application method, but the effect of dolomite was relatively better when applied separatly, especially at the lowest pH-level.

- In both crops concentration and uptake of Mg generally increased by Mg application and the rate of increase was in the order kieserite > brucite > dolomite.

- Concentration of Mg was little affected by pH level or application method but uptake of Mg was increased by higher pH level and regarding dolomite also by separate application.

Lay out of experiment.

pH-levels: 6 and 7.5 by adding $CaCO_3$

Treatments:
a. NPK 22-2-12 with 4% S without Mn
b. - - - " - - - with 0.6% Mn incorporated
c. - - - " - - - with 1.2% Mn - " -
d. As treatm. a with 0.6% Mn applied separately
e. - " - with 1.2% Mn - - " - -

N level: 24 kg N daa^{-1}

Application methods:
A. Mixed into the soil
B. Band placement of fertilizer in a circle 4-5 cm from the pot wall and 1-2 cm under the seed.
Application was done before sowing.

The treatments were replicated three times. A micronutrient mixture containing Fe, Cu, B and Mo as well as an extra dose of P and K at a rate of 3 and 9 kg daa^{-1} respectively were given to each pot. Oat was sown 4 days after application of all fertilizers. The moisture content in the pots was maintained by regular watering with deionized water. The dry matter yield of grain and straw of oat were recorded.

Crop yield

The grain and straw yields of oat were not affected by Mn either applicated separatedly or incorporated in NPK. The grain yield was significantly higher at the lowest pH level and at band placement of fertilizers compared to fertilizers mixed with the soil (Table 7.2. and 7.3.).

Fertilizer mixed in to the soil resulted in higher concentration and uptake of Mn in crop yield than band placement of fertilizer. This was the case when Mn was applied incorporated in NPK as well as applied separatly. However, the application method made no difference in the uptake of Mn in grain yield because of higher grain yield by band placement of fertilizers.

Table 7.4. Effect of Mn-enriched NPK on Mn conc.(mg kg^{-1}) in oat grown at two pH levels and applicated at two methods.

Treat-ment	Grain					Straw				
	pH 6		pH 7.5			pH 6		pH 7.5		
	Mix.	Plac.	Mix.	Plac.	Mean	Mix.	Plac.	Mix.	Plac.	Mean
a.	150	160	90	84	121c	436	434	201	190	315c
b.	160	171	108	101	135b	493	509	233	222	364b
c.	182	173	108	107	142ab	532	469	265	263	382b
d.	171	171	106	97	136b	496	478	286	252	378b
e.	195	170	128	99	148a	624	543	359	232	440a
Mean	171	169	108	98		516	486	269	232	
Mean (pH):	170a		103b			501a		250b		
Mean (application methods):	140a(mix.)		133a(plac.)			393a(mix.)		359b(plac.)		

Table 7.5. Effect of Mn-enriched NPK on Mn uptake (mg/pot) by oat grown at two pH levels and applicated at two methods.

Treat-ment	Grain					Straw				
	pH 6		pH 7.5			pH 6		pH 7.5		
	Mix.	Plac.	Mix.	Plac.	Mean	Mix.	Plac.	Mix.	Plac.	Mean
a.	6.4	7.1	3.7	3.6	5.2d	15.9	15.5	7.4	7.1	11.5c
b.	7.0	7.2	4.5	4.3	5.7c	18.7	17.9	8.5	8.3	13.3b
c.	7.6	7.7	4.5	4.6	6.1b	19.4	17.1	9.5	9.9	14.0b
d.	7.5	7.7	4.3	4.1	5.9bc	18.3	17.6	10.1	9.3	13.8b
e.	8.3	7.8	5.4	4.2	6.5a	21.9	19.2	12.8	8.6	15.7a
Mean	7.4	7.5	4.5	4.2		18.8	17.5	9.7	8.6	
Mean (pH):	7.4a		4.3b			18.1a		9.2b		
Mean (application methods):	5.9a(mix.)		5.8a(plac.)			14.2a(mix.)		13.1b(plac.)		

Conclusions

- No effect of applied Mn on grain and straw yields.

- Concentration and uptake of Mn in total crop yield increased by all Mn treatments at both pH levels and when the fertilizers was mixed in to the soil as well as band placed.

- The highest quantity of Mn added separatly resulted in the highest concentration and uptake of Mn in grain as well as straw yields.

- Fertilizer mixed in to the soil resulted in the highest concentration and uptake of Mn in total crop yield but band placement resulted in the highest grain yield.

Treatments and Experimental Procedures:

Phosphorus Levels:

PO: 0 kg daa^{-1}
P1: 1 kg daa^{-1}
P2: 3 kg daa^{-1}

Nitrogen Levels:

For cereals	For grasses
N1: 6 kg daa^{-1}	8 kg + 4 kg daa^{-1}
N2: 10 kg daa^{-1}	12 kg + 8 kg daa^{-1}
N3: 14 kg daa^{-1}	16 kg + 12 kg daa^{-1}

In addition to the basal dressing; 4, 8 and 12 kg N daa^{-1} in the treatments N1, N2 and N3, respectively, were top-dressed after first cutting of grasses. Potassium at the rates of 8 and 15 kg daa^{-1} in cereals and grasses, respectively, was applied as a basal dose. The fertilizer sources for N, P and K were calcium nitrate, superphosphate and potassium chloride, respectively.

A split plot design with N in the main and P in the sub plots was used and the treatments were replicated 3 times. The subplot size for both cereals and grasses was 20 m^2 (2.5x8 m) with a net harvesting area of 9.75 m^2 (1.5x6.5 m).

The soil samples collected, prior to planting of the crops, from 0-20 and 20-40 cm depths of each block were analyzed for pH, organic C, AL-extractable P and K, and exchangeable cations. The chemical properties of the soils collected from the sites where the experiment was started in the previous

Table 8.1. Effect of P and N on grain yield in previously heavily fertilized soil, kg daa^{-1}.

	N6	N10	N14	MEAN
S12203	INGVAR LYCHE, SØNDRE ØSTFOLD FSR (Oat)			
P0	415	359	354	376ab
P1	481	358	366	402a
P3	388	388	324	367b
MEAN	428a	368b	348b	
S12222	AAGE HOMB, TOTEN FSR (Wheat)			
P0	394	466	558	473a
P1	340	490	524	451a
P3	410	480	531	474a
MEAN	381c	479b	538a	

	N2	N6	N10	MEAN
S12225	GJERMUNDNES LBS. RAUMA - VESTNES FSR (Barley)			
P0	186	253	348	262b
P1	207	290	366	288a
P3	194	299	414	302a
MEAN	196c	281b	376a	

As last year total dry matter yield of grasses responded significantly to applied P at Nesset site, but this was the case only in 2. cut at Jæren site in a newly established meadow. There was also positive response to P in 2. cut at some of the other sites.

N application of 12 + 8 kg daa^{-1} increased total dry matter yield of grasses at most of the sites, but this response of N was significant only at Nesset site. In 2. cut 12 + 8 kg N daa^{-1} resulted in significant increase of dry matter yield of grasses at three of the sites (Table 8.2).

Table 8.2 (continues)

	N8+4	N12+8	N16+12	MEAN
Grass 2.cut				
P0	369	423	398	397b
P1	383	469	449	434a
P3	401	483	480	455a
MEAN	385b	458a	443a	
Grass, sum of 1. og 2. cut				
P0	1098	1170	1095	1121b
P1	1105	1208	1188	1167ab
P3	1160	1242	1238	1214a
MEAN	1121b	1207a	1173ab	

S12213 JOHN HANSEN, LOFOTEN FSR

	N8+4	N12+8	N16+12	MEAN
Grass 1.cut				
P0	426	427	406	420a
P1	432	427	370	410a
P3	455	420	369	415a
MEAN	438a	425a	382a	
Grass 2.cut				
P0	214	321	292	276a
P1	227	350	322	299a
P3	234	310	390	311a
MEAN	225b	327a	334a	
Grass, sum of 1. og 2.cut				
P0	640	748	698	695a
P1	659	777	692	709a
P3	689	730	759	726a
MEAN	662a	752a	717a	

S12214 MIKAL GODTFREDSEN, MIDT-AGDER FSR

	N8+4	N12+8	N16+12	MEAN
Grass 1.cut				
P0	563	540	529	544a
P1	625	545	516	562a
P3	542	568	531	547a
MEAN	577a	551ab	526b	
Grass 2.cut				
P0	260	293	263	272a
P1	244	311	320	292a
P3	225	327	393	315a
MEAN	243b	310a	325a	
Grass, sum of 1. og 2.cut				
P0	822	833	793	816a
P1	870	856	836	854a
P3	767	896	924	862a
MEAN	820a	861a	851a	

yield at all sites. Potatoes do not respond significantly either to P or N application at Toten site in 1992 (Table 8.3).

Table 8.3. Effect of P and N on grain yield of crops grown in previously heavily fertilized soil over a number of years.

	1989	1990	1991	1992	1993
S12203 INGVAR LYCHE, SØNDRE ØSTFOLD FSR					
		OAT	WHEAT	BARLEY	OAT
N 6	329b	514c	412c	193b	428a
N10	378a	560b	480b	177c	368b
N14	387a	574a	519a	211a	348b
P 0	357a	540b	462b	196a	376ab
P 1	368a	545b	479a	198a	402a
P 3	368a	563a	471ab	187a	367b
S12222 AAGE HOMB, TOTEN FSR					
		BARLEY	BARLEY	POTATOES	WHEAT
N 6		329c	364b	971a	381c
N10		418b	465a	953a	479b
N14		463a	440a	940a	538a
P 0		387b	420a	945a	473a
P 1		406a	426a	939a	451a
P 3		416a	424a	981a	474a
S12225 GJERMUNDNES LBS. RAUMA - VESTNES FSR					
		GR.FORAGE	BARLEY	BARLEY	BARLEY
N 2		304a	352c	286c	196c
N 6		346a	477b	394b	281b
N10		337a	515a	464a	376a
P 0		329a	446a	379a	262b
P 1		329a	445a	384a	288a
P 3		328a	453a	381a	302a

Table 8.4 (continues)

S12212 OLE HARALD AARSTAD, NESSET FSR

GRASS	1 cut	2 cuts	2 cuts	2 cuts	2 cuts
N 8	253a	1196b	1264a	1050a	1121b
N12	256a	1276a	1222a	1066a	1207a
N16	247a	1248a	1217a	1044a	1173ab
P 0	249a	1222a	1209a	1001b	1121b
P 1	251a	1256a	1243a	1071a	1167ab
P 3	256a	1243a	1250a	1089a	1214a

S12213 JOHN HANSEN, LOFOTEN FSR

	1989	1990	1991	1992	1993
GRASS	-	2 cuts	2 cuts	2 cuts	2 cuts
N 8		1045a	861a	605a	662a
N12		1045a	848a	626a	752a
N16		1046a	858a	593a	717a
P 0		997a	838a	590a	695a
P 1		1065a	849a	588a	709a
P 3		1074a	881a	645a	726a

S12214 MIKAL GODTFREDSEN, MIDT-AGDER FSR

GRASS	2 cuts	2 cuts	2 cuts	2 cuts	2 cuts
N 8	989	1033a	749a	607ab	820a
N12	995	997a	730a	625a	861a
N16	975	1005a	729a	578b	851a
P 0	1000	1002a	722a	598a	816a
P 1	974	1010a	738a	602a	854a
P 3	985	1023a	747a	610a	862a

S12216 BRIT OG ROLF LUNDVANG, MIDT-HELGELAND FSR

GRASS	1 cut	2 cuts	2 cuts	2 cuts	2 cuts
N 8	148b	1003a	825a	789b	1063a
N12	168a	1037a	880a	827a	1082a
N16	179a	1033a	892a	824ab	1055a
P 0	159a	1042a	877a	835a	1072a
P 1	171a	1016a	873a	807a	1092a
P 3	164a	1016a	846a	799a	1036a

Table 8.5. Uptake of N and P by grain crops as effected by N and P application in previously heavily fertilized soil, kg daa^{-1}.

S12203 INGVAR LYCHE, SØNDRE ØSTFOLD FSR

	Kjeldahl N			Total P		
	N6	N10	N14	P0	P1	P3
1991	6.42c	8.65b	10.45a	1.65a	1.66a	1.63a
1992	3.77b	3.76b	4.62a	0.71a	0.69a	0.65a
1993	7.99a	8.14a	8.06a	1.68a	1.80a	1.71a

S12222 AAGE HOMB, TOTEN FSR

	Kjeldahl N			Total P		
	N6	N10	N14	P0	P1	P3
1991	4.74b	7.02a	7.22a	1.66a	1.63a	1.65a
92(potatoes)	-	-	-	2.59a	2.68a	2.69a
1993	7.04b	9.53a	11.00a	1.90a	1.80a	1.88a

S12225 GJERMUNDNES LBS. RAUMA - VESTNES FSR

	Kjeldahl N			Total P		
	N2	N6	N10	P0	P1	P3
1991	4.39c	6.75b	8.47a	1.61a	1.58a	1.67a
1992	4.69c	6.42b	8.26a	1.48a	1.47a	1.44a
1993	2.90c	4.30b	6.82a	1.05a	1.14a	1.20a

Conclusions

- Significant respons to P application in grain crops has been found at all sites, but only for one or two years of the research period. Generally, N rates up to highest level have resulted in significant increase in grain yield at all sites.
- P uptake was not affected by P application in grain crops, but higher rates of N resulted in increased N uptake as well as P uptake.

- Positive response to P application has been observed in grasses at most of the sites and the response has been significant at Nesset and Jæren sites for two years. Generally, there has been positive response to the medium N rate at most of the sites, but at some sites for some years no response to increased N rates has been found.

- Mostly, uptake of P in grasses was increased by P fertilizing and it was also positively influensed by higher N rates. Uptake of N in grasses increased significantly by higher N rates at all sites with only few exceptions.

N level corresponding to 360 kg ha^{-1} was established by adding ammoniumnitrate.

Treatments:

pH levels: 5.0 and 6.0

N levels: 240 and 360 kg ha^{-1}

Si treatments: a. Without Si

b. 250 kg Si ha^{-1} (1000 kg wollastonite)

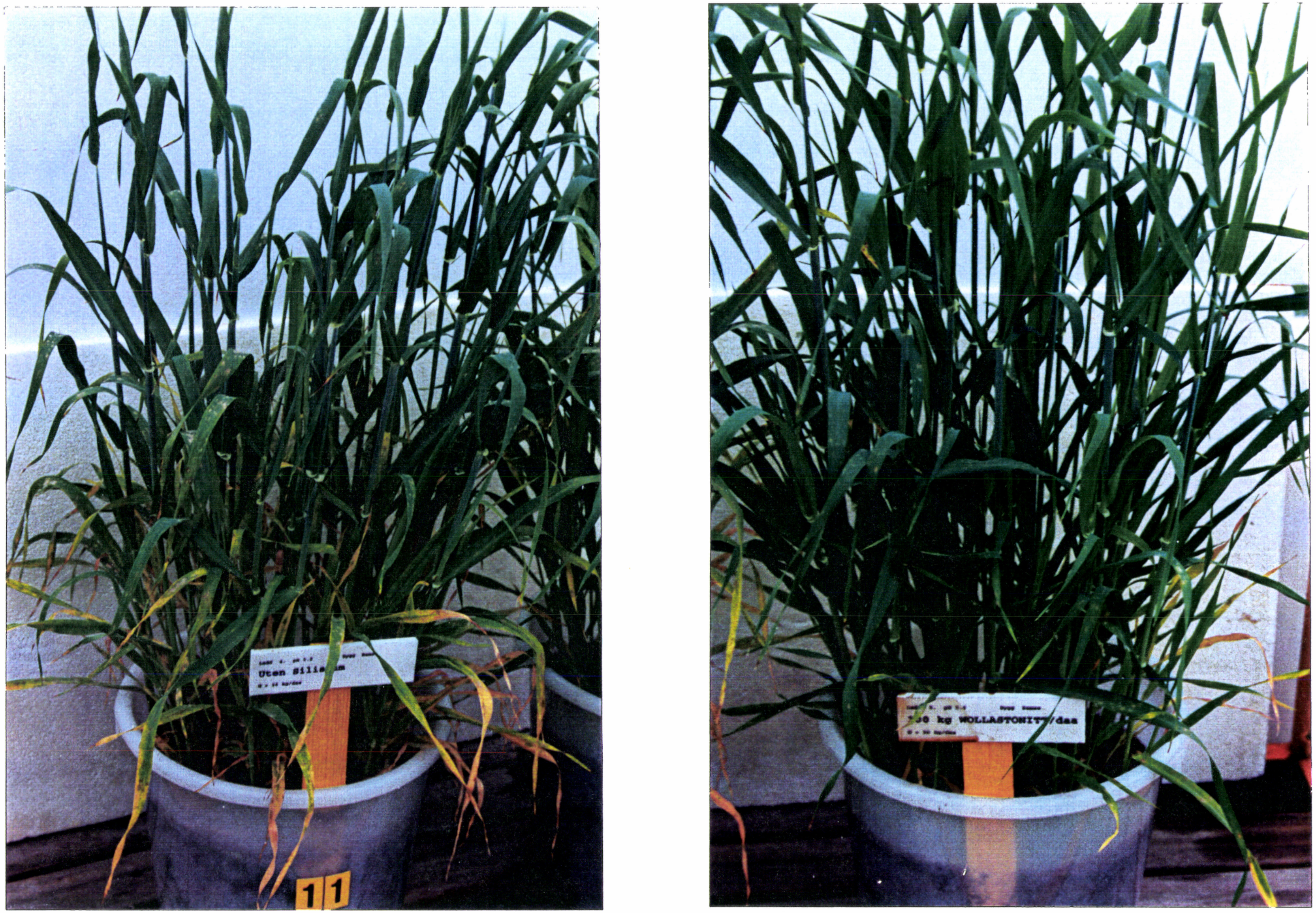
c. 500 kg Si ha^{-1} (2000 kg wollastonite)

All fertilizers were mixed with the soil before sowing of barley (variety: Bamse). All treatments were replicated three times. All pots were top-dressed by calsiumnitrate at early heading stage of barley corresponding to 60 kg N ha^{-1}.

Effect of silisium against powdery mildew.

The attack of powdery mildew was evaluated in percent of the plants leaf area covered by the fungi. The attack started about 16.july after heading of the barley plants. First observation was taken 22.july and the last one 2.august (Table 9.2.).

Without Si the plants were heavely attacked on the lower half part already 22.july. The attack was not so strong at pH 6 as pH 5 but this became more evenly later on. Only the oldest leaves of the plants were attacked in the Si treated pots. 2.august the attack was expanded, but plants in treatments without Si only was attacked on the upper leaves. The attack of powdery mildew was still distinct delayed and reduced by the two treatments with wollastonite. The effect of wollastonite was somewhat better by use of doble quantity. (Picture 9.1).



Picture 9.1 Effect of Si against Powdery Mildew in Barley.

Left: Without Si. Right: With Si corresponding to 250 kg ha^{-1}.

Crop yield

Grain and straw yields were greatly and significantly increased by addition of Si (Table 9.4). The effect of Si was good at both levels of N as vel as pH. The growth was somewhat better and more evenly at the lowest pH level. At this pH level grain yield increased 38 % by use of 250 kg Si ha^{-1} in average of the two N levels. Grain yield in percent of total dry matter yield as vel as weight of 1000 grains were increased significantly by Si supply. Crop yield was increased further by doble quantity of Si (500 kg Si ha^{-1}) but this effect was not significant.

Table 9.4. Effect of Si on dry matter yield of barley grown in sphagnum peat, g/pot

	pH 5		pH 6		
N level, kg ha^{-1}:	240	360	240	360	Mean
		Grain yield			
Without Si	19.5	28.1	21.5	24.6	23.4b
250 kg Si ha^{-1}	27.8	38.1	25.2	34.7	31.5a
500 kg Si ha^{-1}	31.9	40.8	26.8	35.7	33.8a
Mean	26.4	35.7	24.5	31.7	
Mean (pH)	31.0a		28.1b		
		Straw yield			
Without Si	26.1	32.2	27.9	31.0	29.3b
250 kg Si ha^{-1}	30.8	35.9	26.4	33.3	31.6ab
500 kg Si ha^{-1}	31.1	39.8	27.9	36.2	33.8a
Mean	29.3	36.0	27.4	33.5	
Mean (pH)	32.7a		30.4a		

Nutrient concentration and uptake

Application of Si resulted in higher Si concentration, lower concentration of N, P and K and no influence on Ca concentration in dry matter (Table 9.5 - 9.9). Uptake of all these nutrients were significantly increased by Si application because of higher crop yield. The increase in Si uptake by treatment b (800 mg pot^{-1} / 250 kg Si ha^{-1}) was corresponding to 48.8 kg ha^{-1} in average of pH and N levels (Fig.9.1). Accordingly, the availibility of Si in Wollastonite has been quite good.

Concentration and uptake of Si as well as Ca were positively influenced by increased liming. The highest level of lime made variable influence on concentration of N, P and K, but the uptake of these nutrients were reduced by liming.

Concentration of Si was mostly positively influenced and uptake of Si was significantly increased by higher N-rate. Higher N rate resulted also in higher concentration of N and reduced concentration of P, K, and Ca, but the uptake of all these nutrients were increased with exception of P.

Table 9.5. Effect of Si on conc. of Si in barley (mg/kg).

	pH 5		pH 6		
N level, kg ha^{-1}:	240	360	240	360	Mean
		Grain yield			
Without Si	178	113	198	1095	396b
250 kg Si ha^{-1}	576	522	1074	1834	1002ab
500 kg Si ha^{-1}	908	704	1482	3115	1552a
Mean	554	446	918	2015	
Mean (pH)	500b		1466a		
		Straw yield			
Without Si	918	608	998	5359	1970a
250 kg Si ha^{-1}	4375	3249	7956	9484	6266a
500 kg Si ha^{-1}	1122	4513	7394	8686	5429a
Mean	2138	2790	5449	7843	
Mean (pH)	2464a		6646a		

Table 9.6. Effect of Si on conc. of N in barley (g/100g).

	pH 5		pH 6		
N level, kg ha^{-1}:	240	360	240	360	Mean
		Grain yield			
Without Si	1.13	1.47	1.45	1.49	1.38a
250 kg Si ha^{-1}	1.24	1.28	1.38	1.37	1.32a
500 kg Si ha^{-1}	1.35	1.40	1.31	1.42	1.37a
Mean	1.24	1.38	1.38	1.43	
Mean (pH)	1.31a		1.40a		
		Straw yield			
Without Si	0.57	0.66	0.51	0.53	0.57a
250 kg Si ha^{-1}	0.38	0.40	0.31	0.32	0.35b
500 kg Si ha^{-1}	0.34	0.34	0.30	0.33	0.33b
Mean	0.43	0.47	0.37	0.39	
Mean (pH)	0.45a		0.38b		

Table 9.9. Effect of Si on conc. of Ca in barley (g/100g).

N level, kg ha^{-1}:	pH 5 240	pH 5 360	pH 6 240	pH 6 360	Mean
			Grain yield		
Without Si	0.050	0.044	0.051	0.049	0.048a
250 kg Si ha^{-1}	0.049	0.042	0.050	0.043	0.046a
500 kg Si ha^{-1}	0.043	0.043	0.048	0.048	0.046a
Mean	0.047	0.043	0.049	0.047	
Mean (pH)	0.045a		0.048a		
			Straw yield		
Without Si	0.769	0.619	0.839	0.928	0.789a
250 kg Si ha^{-1}	0.838	0.649	0.878	0.686	0.763a
500 kg Si ha^{-1}	0.707	0.713	0.890	1.039	0.837a
Mean	0.771	0.660	0.869	0.884	
Mean (pH)	0.716b		0.877a		

Conclusion.

- Grain yield of barley increased significantly in mean of pH and N levels by addition of Si to sphagnum peat. The effect of Si was best at the low pH level and the highest N rate.

- Grain yield in percent of total dry matter yield and weight of 1000 grains were increased significantly by application of Si.

- Si application resulted in higher concentration and uptake of Si as well as higher uptake of N, P, K and Ca in crop yield.

- The attack of powdery mildew was reduced and delayed by the treatments with Si. This must be the main reason for increased crop yield because the plants then had a longer period of assimilation.

- Si application resulted in bigger nodes and higher stiffness of straw.