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Annual Research Report

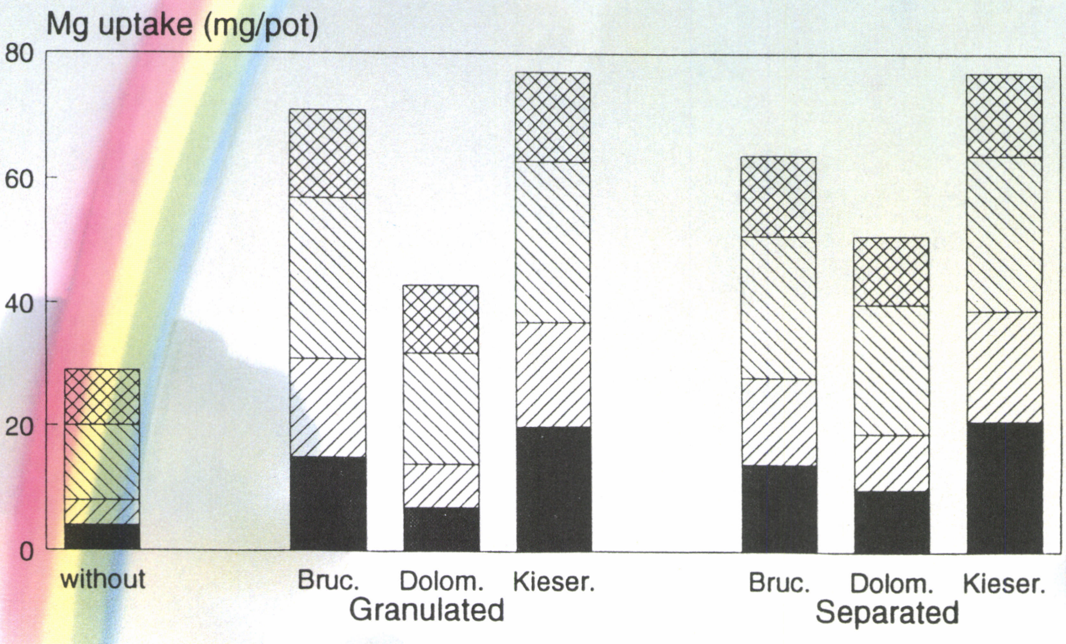
1994

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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FERTILIZER RESEARCH PROGRAM

(IJVF - NORSK HYDRO a.s.)

Leif Ruud

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This report describes the results of the greenhouse and field experiments conducted in the cropping season of 1994 by the Department of Soil and Water Sciences, Agricultural University of Norway, in co-operation with 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

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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 results from nine research projects including many 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 1994 following research project are included in the program: Effect of selenium-enriched calsium nitrate on the selenium concentration in wheat; 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; effects of sulpher-enriched calsium nitrate on crop yield and concentration of nutrients in dry matter; the effects of manganese incorporated in NPK fertilizer; effects of cobalt incorporated in NPK and calsium nitrate on cobalt concentration in meadow grasses.

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

Leif Ruud

SAMMENDRAG AV FORSØK UTFØRT 1994

Rapporten for 1994 omfatter 9 hovedavsnitt som beskriver resultater fra forsøksserier utført i våre kar- og markforsøk. Et kort sammendrag av forsøksresultatene følger nedenfor.

1. SELEN-HOLDIG KALKSALPETER VED TILLEGGSGJØDSLING AV HVETE

Norsk hvete innholder lavere mengder av Sè enn det som trengs i mathvete. Formålet med denne forsøksserien er å undersøke virkningen av Sè-holdig kalksalpeter på Sè-innholdet i mathvete.

Forsøk i vårhvete.

Som bakgrunn for feltforsøkene ble det først startet opp en karforsøksserie i veksthuset som ble avsluttet i 1991. Inklusiv 1994 som var det 5. forsøksåret, er det utført i alt 24 enkeltfelter i vårhvete.

- Selèninnholdet i hvete ble mangedoblet ved tilførsel av Sè-holdig kalksalpeter, men utslagene for Sè-gjødsling varierte fra felt til felt og fra år til år.

- Bruk av Sè-holdig kalksalpeter ved begynnende skyting ga generelt like godt resultat som Sè-holdig Fullgjødsel gitt om våren. Under spesielt tørre vekstforhold har Sè-tilførsel om våren vært fordelaktig, mens Sè-holdig kalksalpeter ved skyting ofte har gitt det beste resultat når plantenes vekst og utvikling er normal.

- Vanligvis er Sè-innholdet i vårhvete økt til ønsket nivå ved bruk av kalksalpeter med 25 mg Se kg^{-1}, 25 kg vare daa^{-1}. Effekten varierer med jordtype og særlig klima-forholdene.

- På feltet i Solør-Odal ble det også sikker avlingsreduksjon når P var utelatt fra gjødsla, mens grasavlingene på Vågønes-feltet ble sikkert redusert når det ikke ble gjødslet med S.

- N-innholdet ble redusert i både gras og korn uten N-gjødsling. I gras ble også innholdet av de andre næringsstoffene generelt redusert når de ikke ble tilført.

K-tilgangen påvirket plantenes innhold av både Mg, S, P og N.

3. 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 8 fastliggende felt i korn og eng. Resultatene så langt er kort oppsummert nedenfor:

- På kornfeltene er det funnet sikre avlingsutslag for gjødsling med superfosfat i bare noen av forsøksårene. N-gjødsling har generelt gitt sikker avlingsøkning i korn opp til største mengde.

- Gjødsling med superfosfat påvirket ikke P-opptaket på kornfeltene, mens økt N-gjødsling ga både økt N- og P-opptak i avlingen.

- Det har vært positive avlingsutslag for gjødsling med superfosfat på alle engfeltene ett eller flere år. I Jæren FSR og Nesset FSR har superfosfat gitt **sikre** avlingsutslag i 3 av forsøksårene. De fleste engfeltene har som regel gitt avlingsøkning opp til midlere N-mengde (12+8 kg daa^{-1})

- Både innholdet og opptaket av P i engavlingene er blitt lite, men positivt påvirket av gjødsling med superfosfat

5. EFFEKTEN AV ULIKE NITROGENGJØDSELSLAG MED OG UTEN SVOVEL

I 1994 ble det startet opp både kar og markforsøk, men bare karforsøkene i raigras er beskrevet i denne rapporten.

- Til tross for meget S-fattig jord ble det ikke avlingsutslag for S, men derimot sikre meravlinger på alle kalksalpeterledd med eller uten S. På disse leddene økte jordas pH så vel som Ca-innholdet i både jord og planter.

- Kalksalpeter med kieseritt ga høyest innhold og opptak av Mg og S i raigraset, mens innholdet og opptaket av N, K og Ca var like stort som i vanlig kalksalpeter.

- Kalksalpeter med og uten S reduserte K/Ca+Mg forholdet i avlingen.

6. BRUCITT SOM Mg-KILDE

Brucitt består av 95% $Mg(OH)_2$ og har høyere vannløslighet enn dolomitt. Ved hjelp av karforsøk blir det vurdert om brucitt er en aktuell Mg-kilde ved produksjon av Fullgjødsel.

Forsøk i havre og raigras

- Alle Mg-kildene ga sikker avlingsøkning både i raigras og havre, men økningen var betydelig større ved bruk av kieseritt og brucitt enn ved bruk av dolomitt.

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

- Mn-opptaket har blitt sterkt redusert på alle ledd ved høgt pH-nivå i jorda.

- Mn-opptaket har ikke entydig blitt påvirket av spredemetoden eller om Mn er tilført separat eller inngranulert i gjødsla.

8. EFFEKTEN AV KOBOLT-HOLDIG FULLGJØDSEL PÅ KOBOLT-INNHOLDET I BEITEGRAS.

Noen tilfeller av dårlig tilvekst hos lam som kan skyldes koboltmangel i graset, er funnet langs kysten i Vest-Norge. Det er derfor interessant å teste virkningen av Co-holdig Fullgjødsel på Co-innholdet i beitegras under ulike dyrkingsbetingelser. Det er utført forsøk både i kar og i felt. Da karforsøkene er avsluttet og rapportert tidligere, er bare feltforsøkene omtalt i denne rapporten.

- 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.

- Co-innholdet i graset har generelt vært noe høyere ved laveste pH-nivået i jorda.

- I motsetning til i 1992 var Co-innholdet i graset i 1993 og 94 ikke høyere i 1. slått enn i 2. og 3. slått.

- Graset på de fleste feltene har hatt lavt Cu-innhold, men innholdet har økt noe ved redusert pH-nivå i jorda. Høyere Cu-innhold i gjødsla har ofte bare gitt svak økning av Cu-innholdet i graset.

SUMMARY AND CONCLUSIONS

The research report 1994 is describing research projects carried out in pot and field experiments at Department of Soil and Water Sciences and in collaboration with other research institutions in Norway. A brief summary of the results from the experiments is presented here.

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

Experiments in Spring Wheat:

- In average of 24 test fields in wheat through 1990-94 concentration of Sè in grain increased by many times when Sè-enriched fertilizers were applied.

- 25 mg Sè kg^{-1} CN top-dressed at heading (26 kg daa^{-1}) was found to encrease Sè concentration in wheat grain to desired level in all test locations.

- There was variation in Sè concentration in wheat grain from site to site and from year to year at all treatments. This is caused by different climates and soils, but no consistent relationship is found in this material.

- Generally, Sè-enriched CN top-dressed was found as effective as basal application of Sè-enriched NPK in increasing Sè-concentration in grain yield.

Experiments in Winter Wheat:

- Top-dressed Sè-enriched CN increased Sè concentration in winter wheat grain many times in all field trials 1994.

- Concentration of N was generally lower in grain crops as well as grass crops when nitrogen was missing from the fertilizer applied.

- In the grass fields concentration of all nutrients tended to be lower if they were not added through fertilizers.

- Generally, concentration of Mg as well as S, P and N are going to be increased if K is missing in the fertilizer.

3. PHOSPHORUS SUPPLYING CAPACITY OF PREVIOUSLY HEAVILY FERTILIZED SOILS AT INCREASING RATE OF N APPLICATION

- Grain yields have increased significantly by application of superphosphate at all sites, but only for one or two years of the research period. Generally, N rates up to the highest level have resulted in significant increase in grain yield at all sites.

- P concentration and uptake have not been affected by application of superphosphate in cereals, but higher rates of N resulted in higher P uptake as well as higher uptake and concentration of N.

- Positive response by application of superphosphate has been observed in grasses at most of the sites and the response has been significant at Nesset and Jæren sites for three years. In four of the grass field experiments in 1994 crop yield responded significantly to application of superphosphate.

- Generally, there has been positive response to the medium N rate in grasses at most of the sites, but at some sites for some years no response to increased N rates has been found.

- S application resulted in a strong reduction in concentration of nitrate in dry matter yield of ryegrass.

- N/S ratio expressed in g kg^{-1} dry matter was very high without and with only little S applied being reduced to normal level by application of S to ryegrass as well as barley.

5. EFFECT OF SULPHER-ENRICHED NITROGEN FERTILIZERS ON CROP YIELD AND NUTRIENT CONCENTRATION IN RYEGRASS

- Ryegrass yield was significant highest in all CN treatments. These treatments increased soil pH and Ca content in plant and soil.

- Concentration of Mg, Ca and S in crop yield were increased in relation to application of these nutrients through the treatments.

- CN treatments with kieserite added resulted in highest concentration and uptake of Mg and S in crop yield and as high concentration and uptake of N, K and Ca as ordinary CN.

- All CN treatments reduced K/Ca+Mg ratio in crop yield.

6. EFFECT OF BRUCITE AS A MAGNESIUM-SOURCE

Test in oat and ryegras:

- Crop yield of oat and ryegrass increased significantly by 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

Pot experiment II:

- Application of Mn resulted in increased concentration and uptake of Mn in grain and straw yield but it had no effect on crop yield.

Pot experiment III:

- Grain yield was increased by application of 1.2% Mn incorporated in NPK, but straw yield was highest without Mn added.

- Mn concentration and uptake in crop yield were increased by all Mn treatments up to the highest Mn rate at both pH level.

- The effect of Mn added was best by band placement of fertilizers but in any case the recovery of Mn was small.

- Mn concentration and uptake in crop yield were strongly reduced at the highest pH level.

8. EFFECT OF COBALT-ENRICHED NPK ON COBALT CONCENTRATION IN MEADOW GRASSES

- Co concentration in plants in the control plots has been below the level considered adequate for animal fodder at most of the sites.

- Similar to the greenhouse experiment, Co concentration in plants increased with increased rate of Co in the fertilizer applied in all field experiments.

- Generally, Co concentration in plants has been slightly higher at the lowest soil pH level at all sites.

Field Experiments:

- Co concentration and uptake in plants increased by all Co treatments.

- Liming had little effect on soil pH and Co concentration in plants at Særheim site, but the effect of applied Co was best without liming at Fureneset.

- Co-enriched NPK increased Co concentration and uptake in crop yield some more than Co-enriched CN.

- Repeated Co application after 1. harvest resulted in unessecary high concentration of Co in 2. harvest, but good residual effect in 3. harvest.

- Half rate of Co had good effect in 1. harvest at Fureneset site, but little effect at Særheim site. After repeated application the effect on Co concentration was good in 2. and 3. harvests.

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

Selenium (Se) is an essential nutrient for men and animals, but it is not necessary for plants. Because crops grown in the nordic countries are extremely low in Se, feed concentrates are added Se to cover livestock requirements. Still, the Se supply to men and grazing animals could be a problem. Therefore, the effect of Se-enriched fertilizers on the Se concentration in plants has been tested in Norway in many years. At first Se-enriched NPK fertilizers were tested with good results in cereals and grass. Se-enriched calsium nitrate (CN) are tested as an alternative because CN is used for top dressing in many crops. Then the demand for Se can be met with one fertilizer.

FIELD EXPERIMENTS IN SPRING WHEAT

When Se-enriched CN was tested in greenhouse Se concentration in wheat increased in proportion to the rate of Se applied. Under field conditions Se-enriched CN has been tested mostly in spring wheat since 1990. The fields have been laid out at seven locations representing different soils and climates in the cereal growing areas of Norway. It has been concluded that Se-enriched CN is an effective fertilizer to increase Se concentration in wheat to desired level. The results from the field tests in 1994 presented in this report are conforming this conclusion.

In 1994 two field experiments were laid out at Department of Soil and Water Sciences, Ås, one at the Agricultural Experimental Station Kvithamar and one at a farmer's field in the Agricultural Experimental Group Stjørdal. The two fields at Ås are permanent with a rotation of wheat and other cereals.

applied in treatment b. CN with and without Se was top-dressed at the initiation of heading.

The crops were harvested at maturity and threshed to separate grain and straw, but grain samples only were analyzed for Se.

Crop yield

Similar to the previous years the grain yield (Table 1.2) was not significantly affected by application of Se-enriched CN or NPK. The exception for treatment b at Kvithamar must be due to other reasons. The low level of wheat grain yields at Ås are caused by unfavourable climate conditions in the growing season.

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

Experimental site		Treatment		
	a	b	c	d
Ås I (wheat)	252a	244a	264a	250a
Kvithamar "	443a	411b	436a	446a
Stjørdal "	295a	356a	330a	305a
Ås II (oat)	341a	320a	317a	349a

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

Selenium Concentration and Uptake

Concentration of Se in grain crops (Table 1.3 and fig. 1.1) increased progressively with increased rates of Se incorporated in CN on all sites, showing a trend similar to that observed in the previous seasons. However, the level of Se concentration at treatment with Se was rather high this growing season. The reason for the high Se concentration this year could be the extremely hot climate in july and august. However, concentration of Se in the control plots was on the

Table 1.4. Se concentration in wheat grain, mg/kg, in mean of test years as influenced by Se-enriched fertilizers

Site	Period	a	b	c	d
Ås I &II*	90-94	0.016	0.13	0.29	0.25
Øsaker	90-93	0,085	0,18	0.41	0.17
Vestfold	91-92	0,029	0,10	0.30	0.19
Apelsvoll	90,92,93	0.021	0.20	0.44	0.09
Staur	90-93	0.007	0.15	0.45	0.14
Stjørdal	92-94	0.067	0.15	0.40	0.37
Kvithamar	92-94	0.017	0.26	0.58	0.16
Mean of 24 test fields		0.034	0.17	0.41	0.20

Variation:
Treatm. a: 0.005-0.11 (0.17), treatm. b: 0.02-0.40,
treatm. c: (0.05) 0.11-0.93, treatm. d: (0.005) 0.07-0.44
(Extreme values in brackets)

* Permanent fields in rotation with oat and barley

corresponding values for Se concentration in treatment b, c and d then are nearly unchanged, respectively 0.17, 0.40 and 0.18 mg/kg. These mean values for Se concentration are on the same level as find before in field trials with Se-enriched NPK

The total mean values as well as mean values at all locations show a very good response of Se-enriched CN. Se concentration in grain has been raised to desired level by CN with 25 mg Se incorporated per kg and by corresponding amount of Se incorporated in NPK. This good response for Se-enriched CN has been reached in spite of very dry climate conditions at top-dressing at many sites in 1992 and 93.

The variation in Se concentration (Tabell 1.4.) is on the same level as find before in field trials with Se-enriched NPK. The variation is caused by different climate from year to year and between locations and to different soils, but no consistent relationship can be found in this material. It is obvious that top-dressing fail if the plants for instance are suffering under extreme dry conditions.

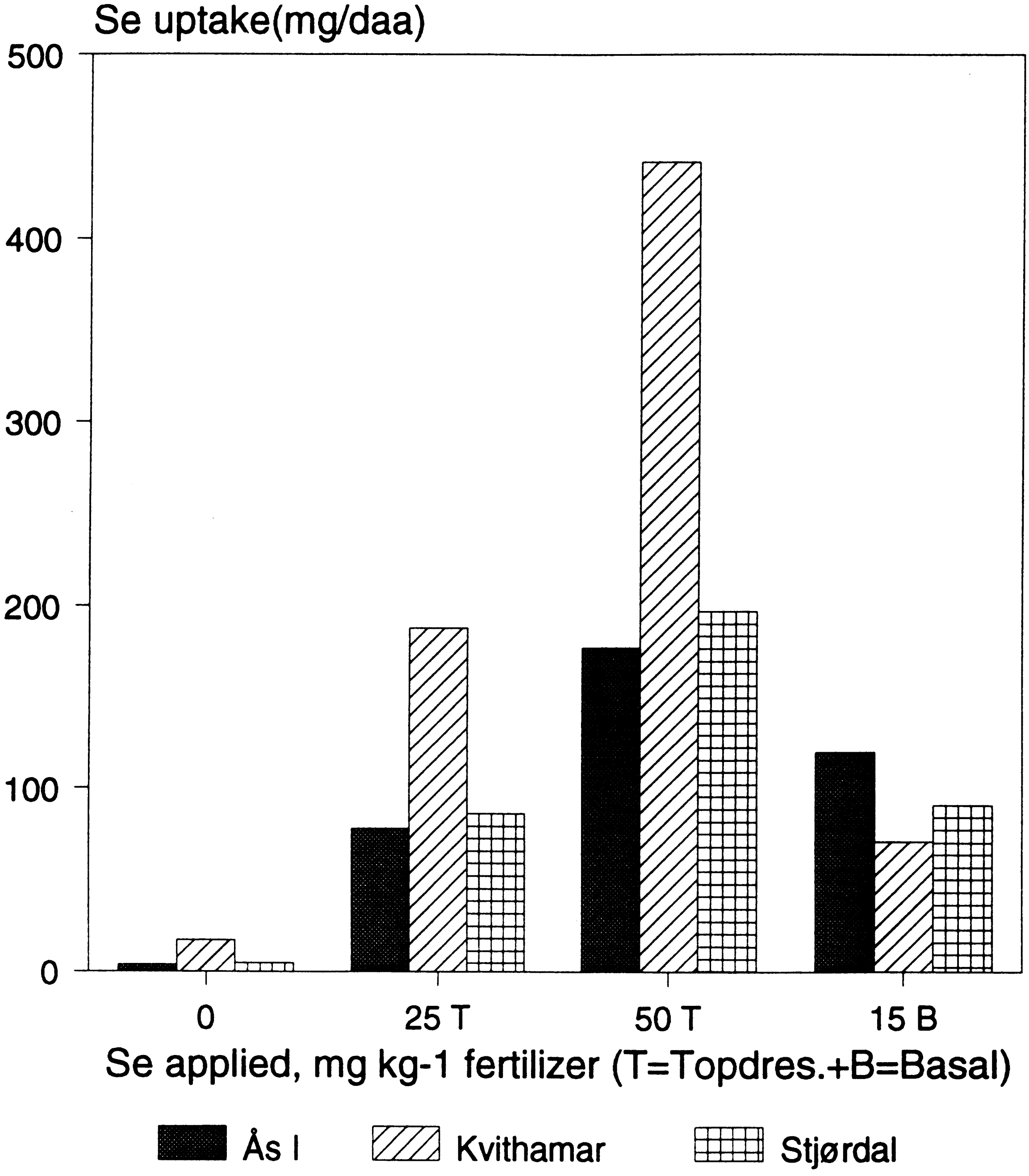

Fig 1.2 Effect of Se enriched CN on
Se uptake by wheat 1994

After basis fertilizing in spring CN was top-dressed at stem elongation (Zadoks 31-32) and ear emergence (Zadoks 50-55). 4 kg N daa^{-1} through CN with 25 mg Sè/kg fertilizer was added in three treatments, at Z 30-31 only, at Z 50-55 only and at both of these stages. CN without Sè was used as control treatment. 12 kg N daa^{-1} in all through CN and Sè-enriched CN was added in each treatments. In addition 3-5 kg N daa^{-1} through NPK was added before sowing.

Concentration of Selenium in grain yield

The crops were harvested at maturity and threshed to separate grain and straw, but grain samples only were analyzed for Sè (Table 1.5).

Table 1.5. Effect of Sè-enriched CN on Sè concentration, mg/kg grain, in winter wheat.

Site	Soil	CN w/out Sè	CN w/Sè Z 30-31	CN w/Sè Z 50-55	CN w/Sè both stag.
Skjeberg	(moraine)	0,040	0,520	0,510	0,980
Vestby	(cley)	0,035	0,450	0,440	0,970
Hole	(cley)	0,010	0,190	0,240	0,380
Nannestad	(cley)	0,015	0,190	0,064	0,220
Ringsaker	(moraine)	0,019	0,390	0,300	0,690
Mean		0,024	0,348	0,310	0,648

CN without Sè added resulted in low concentration of Sè in grain yield as usual in the Nordic countries. Sè-enriched CN applied at early or late stage increased Sè concentration many times. Application of Sè-enriched CN at both stages led to further increase in Sè concentration. At Nannestad site application of Sè-enriched CN at late stage led to lesser increase in Sè concentration than application at early stage. This could be caused by reduced plant vigour due to drought in a long period.

as selenite which is little exposed to leaching. So, the content of Sè in soil is going to increase after fertilizing, but the increase can not be measured by analyzing in many years because it will be very small.

However, better knowledge about possible Sè leaching from added Sè in different soils is desirable. In spring 1993 an experiment with this purpose was started up in a lysimeter field at Department of Soil and Water Sciences.

Lysimeter Experiment 1993

The experiment was done in 4 different soils with 2 water regimes; irrigated and non irrigated, and with 2 replicates. The soils, representing moraine, sandy soil, silt and heavy cley are very good defined and analyzed. The soils are filled into 110 cm deep cylinders with 0.5 m^2 top area and with outlet for leaching water. Including control treatments the experiments consisted of 24 lysimeters.

NPK 18-3-15 corresponding to 9.5 kg N daa^{-1} was added the lysimeters before sowing of barley. In the control treatments N rates were 3 and 16 kg daa^{-1} because of limited capacity of the lysimeter field. Few days after emergence of barley 1.5 mg Na-selenate with 21% Sè mixed in 50 ml water was added each lysimeter. Sè added was corresponding to 630 mg Sè daa^{-1} which are som more than recommended in practical wheat growing.

First water samples taken out 1. of october were representing 60 mm leaching in mai - september period in mean of all soils. The second water samples taken 1. of january were representing mai - december leaching period with 253 mm and 215 mm water respectively in irrigated and non irrigated parts. Precipitation in mai - december period was 631 mm water and in addition 100 mm was added in the growing season in the irrigated part.

2. RESPONSE OF CROPS TO MACRO- AND MICRONUTRIENTS IN PERMANENT FIELDS LOCATED IN SOME DISTRICT OF NORWAY.

This experiment was initiated in 1990 with an objective to demonstrate how crops respond to different nutrients when they are eliminated from the fertilizer applied. It was also of interest to find the time needed to get a response of the applied nutrient in a particular soil. Deficiencies of secondary or micro nutrients have been observed in different crops from time to time in many parts of the country. The nutrients Mg, S and B are generally incorporated in the complete fertilizers during their manufacture process in Norway to safeguard an eventual deficiency problem. It has been argued that most of the crops do not respond to application of these secondary or micro nutrients due to higher fertility levels of most of the soils in Norway and hence the incorporation of these nutrients in the complete fertilizers may not be absolutely necessary. However, fertilization is not only for crop yield quantity but also for quality.

The results from the first four years show that significant yield reductions occurred in the absence of all nutrients except Mg on the fertilization scheme. Absence of all these nutrients including Mg also resulted in reduced content of nutrients in crop yield.

In the first experimental year in 1990 five different sites with different soil types and climatic conditions were initiated. The sites and the major chemical properties of the soils collected from four of these sites have been described in the research report for 1990. Some chemical properties of the soil collected in november 1993 from the fifth site, Vågønes Research Station, are presented in table 2.1. The experiment on these sites were continued in 1991 and 92 and in addition three new sites were initiated in 1992. The major

The amounts of nutrients added in each treatment through these fertilizers are given in table 2.2. Fertilizer rates applied for cereals and meadow grasses were corresponding to 10 respectively 12 kg N daa^{-1} in spring. N and K only were applied after 1. cut in grasses.

Table 2.2. Amounts of different nutrients added when 10 kg N daa^{-1} is applied in cereals.

Treat ment	N	Fert.	P	K	Ca	Mg	S	B	Rem.
	kg/daa							g/daa	-
A	10	53.3	2.40	7.68	1.34	0.69	0.82	13.3	All
B	0.03	33.5	2.35	6.87	2.86	0.87	2.14	+Bor.	÷N
C	10	50.1	0.0	7.62	1.27	0.66	0.13	+Bor.	÷P
D	10	40.1	2.33	0.18	1.33	0.68	0.85	14	÷K
E	10	51.0	2.35	7.40	1.39	0.04	0.82	15.4	÷Mg
F	10	52.5	2.35	7.82	1.37	0.84	0.0	15.6	÷S
G	10	54.1	2.32	7.84	1.33	0.70	0.81	0.0	÷B
H	10	50.5	2.33	7.73	1.31	0.05	-	-	÷Mg,S,B

All test fertilizers were applied as basal dose prior to sowing of cereals or in early spring for grass. The crops grown in 1994 were barley at Apelsvoll and Kvithamar sites, oats at N. Telemark, Ås and Solør-Odal sites and meadow grass at Vågønes and Særheim sites. 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 grain yield was recorded with the exception of the Ås site. Grass was harvested two times and the dry matter yields from both harvests were combined for the total dry matter yield. Both grain and grass samples were collected from each plot but they were later pooled treatment wise for chemical analysis.

K at Særheim site. At Vågønes site absence of S resulted in reduced yield in 1. harvest as well as 2. harvest and the need for S was underlined by the reduced yield when Mg, S and B applied together were missing in the fertilizer scheme.

Nutrient Concentrations

The chemical analysis data for 1994 are presented in tables 2.4 and 2.5. Nutrient concentrations in the crops show some relationship with the treatments, especially in grass. When compared with complete fertilization the concentration of N was generally lower in grain crops as well as grass crops when nitrogen was missing from the fertilizer applied.

In the grass fields at Vågønes and Særheim sites concentration of all nutrients tended to be lower in the treatments without one of these nutrient added. Concentration of Mg increased in grasses at the treatment without K. The high crop yield in 1. harvest at Særheim site resulted in generally low concentration of all nutrients in grasses. There was generally low concentration of S and B in grasses at Vågønes site.

Table 2.4. Concentrations of nutrients in grain crop as influenced by different test fertilizers in 1994.

Treat-ment	N	P	K	Mg	S	B
	%					mg kg^{-1}
(Oats)	Ås					
a	2.02	0.35	0.53	0.12	0.15	1.6
b(÷N)	1.52	0.44	0.53	0.15	0.14	1.5
c(÷P)	2.10	0.35	0.51	0.12	0.19	1.5
d(÷K)	2.08	0.36	0.50	0.13	0.18	1.4
e(÷Mg)	1.99	0.35	0.53	0.12	0.17	1.6
f(÷S)	2.14	0.36	0.49	0.12	0.15	1.3
g(÷B)	2.07	0.34	0.51	0.12	0.18	1.2
h(÷Mg, S & B)	2.07	0.34	0.49	0.11	0.15	1.2
i(control)	1.50	0.43	0.54	0.15	0.13	1.5

Table 2.5. Concentrations of nutrients in grass crop as influenced by different test fertilizers in 1994.

Treat-ment	N	P	K	Mg	S	B
	%					mg kg^{-1}
(Grass, 1.cut)			Vågønes			
a	1.87	0.34	2.18	0.20	0.18	2.0
b(÷N)	1.83	0.32	2.25	0.17	0.15	5.6
c(÷P)	1.90	0.30	2.17	0.14	0.18	2.9
d(÷K)	2.11	0.37	1.06	0.27	0.19	3.3
e(÷Mg)	1.78	0.32	2.15	0.15	0.17	2.5
f(÷S)	1.93	0.30	2.04	0.14	0.10	2.6
g(÷B)	1.82	0.33	2.18	0.15	0.17	2.3
h(÷Mg, S & B)	1.88	0.32	2.14	0.13	0.09	2.4
i(control)	1.48	0.28	1.60	0.21	0.12	3.8
(Grass, 2.cut)						
a	2.10	0.30	1.97	0.28	0.15	2.9
b(÷N)	2.43	0.38	2.65	0.28	0.23	6.3
c(÷P)	1.99	0.28	2.21	0.24	0.14	3.0
d(÷K)	2.57	0.37	0.78	0.49	0.17	3.7
e(÷Mg)	2.10	0.31	2.10	0.26	0.13	2.8
f(÷S)	2.51	0.42	2.19	0.28	0.13	3.0
g(÷B)	2.12	0.31	2.01	0.27	0.15	1.9
h(÷Mg, S & B)	2.66	0.47	2.20	0.24	0.12	2.8
i(control)	2.42	0.45	1.76	0.39	0.21	6.3
(Grass, 1.cut)			Særheim			
a	1.28	0.21	1.64	0.13	0.17	2.3
b(÷N)	0.89	0.21	1.51	0.10	0.16	2.3
c(÷P)	1.25	0.17	1.58	0.11	0.15	2.2
d(÷K)	1.50	0.23	1.14	0.14	0.18	3.2
e(÷Mg)	1.41	0.22	1.69	0.12	0.16	2.5
f(÷S)	1.34	0.20	1.56	0.13	0.13	2.0
g(÷B)	1.37	0.21	1.76	0.13	0.13	2.2
h(÷Mg, S & B)	1.37	0.21	1.72	0.12	0.12	2.1
i(control)	0.85	0.20	1.31	0.11	0.14	2.0
(Grass, 2.cut)			Særheim			
a	1.70	0.29	1.46	0.20	0.22	3.9
b(÷N)	1.52	0.33	2.02	0.18	0.28	6.8
c(÷P)	1.72	0.25	1.47	0.18	0.22	4.9
d(÷K)	1.84	0.30	0.97	0.23	0.23	5.2
e(÷Mg)	1.81	0.31	1.51	0.20	0.22	4.7
f(÷S)	1.78	0.30	1.48	0.20	0.17	4.9
g(÷B)	1.77	0.28	1.54	0.19	0.20	4.1
h(÷Mg, S & B)	1.59	0.30	1.57	0.18	0.17	4.4
i(control)	1.27	0.35	1.83	0.18	0.30	4.5

3. PHOSPHORUS SUPPLYING CAPACITY OF PREVIOUSLY HEAVILY FERTILIZED SOILS AT INCREASING RATE OF N APPLICATION.

The main objective of this study is to evaluate the quantities of P accumulated in the soil over a period of time which could be available to plants and the duration of cropping in which the plant could draw upon the residual P alone or with reduced level of fertilization.

This is a long term study where the assessment of the P supply to plants from the residual P is of great importance both from the points of view of fertilizer recommendations and of the danger of water pollution associated with runoff or erosion losses of P from agricultural lands.

This study was initiated in the cropping season of 1989. All the sites were chosen from previously heavily fertilized soils with varying soil properties and located under different agro-ecological zones of Norway. The study was in 1994 in its sixth year of experimentation. It was conducted at 8 different sites, of which 2 were in cereals and 6 in grasses.

The results from the previous years have shown positive response to superphosphate in grasses at many of the sites and the response has been found significant at two sites for two years. Generally, the response to N application has been found positive up to medium level (20 kg N daa^{-1}) in grasses, being significant at several sites.

In cereals significant response to superphosphate has been found at all sites, but only for one or two years of the research period. Generally, the response to applied N in cereals has been found significant at all sites.

The experimental plans and procedures used has been the same every year and they are presented on next page.

the sites where the experiment was started in the previous years have been described in the Annual Research Reports of 1989, 1990 and 1991.

The cereal crop at all locations was harvested at maturity. Grasses were harvested at the initiation of heading and two cuttings of grasses were taken at all sites. Grass samples were dried at 60-70° C for the determination of dry matter. Both grain and grass samples were analyzed for P and N.

Crop Yield

There was no significant response in grain yield for applied superphosphate at the two fields in cereals in 1994 but the response for 1 kg P daa^{-1} was positive at optimal N application (Table 3.1). The effect of N application on grain yield was

Table 3.1. 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	364	397	415	392a
P1	356	409	430	398a
P3	364	397	429	396a
MEAN	361c	401b	425a	
S12225	GJERMUNDNES LBS, RAUMA & VESTNES FSR (barley)			
P0	150	194	187	177a
P1	145	204	187	178a
P3	152	211	195	186a
MEAN	149b	203a	189a	

Table 3.2 (continues)

	N8+4	N12+8	N16+12	MEAN
S12211	SVEIN A. ØYE, SØRE SUNNMØRE FSR			
Grass 1.cut				
P0	178	243	270	230a
P1	223	247	220	230a
P3	223	261	223	235a
MEAN	208a	250a	237a	
Grass 2.cut				
P0	239	325	258	274ab
P1	224	263	248	245b
P3	283	365	273	307a
MEAN	249b	317a	259b	
Grass, sum of 1. and 2. cut				
P0	418	568	527	504ab
P1	448	509	467	475b
P3	505	626	495	542a
MEAN	457b	568a	497b	
S12212	OLE HARALD AARSTAD, NESSET FSR			
Grass 1.cut				
P0	479	488	486	484a
P1	492	515	458	488a
P3	528	511	496	512a
MEAN	500a	505a	480a	
Grass 2.cut				
P0	285	348	332	322b
P1	281	363	347	330b
P3	327	392	384	368a
MEAN	298b	368a	355a	
Grass, sum of 1. and 2. cut				
P0	764	836	819	806b
P1	773	877	805	819b
P3	855	904	880	880a
MEAN	798b	872a	835ab	
S12213	JOHN HANSEN, LOFOTEN FSR			
Grass 1.cut				
P0	396	270	330	332a
P1	462	297	547	435a
P3	444	390	487	440a
MEAN	434ab	319b	455a	

Since start of the research project superphosphate has resulted in significantly higher grain yield in cereals at S. Østfold site in 1990 and 1991 and at Rauma & Vestnes site in 1993 (Table 3.3). Application of 14 and 10 kg N daa^{-1} at S. Østfold and Rauma & Vestnes sites, respectively, has resulted in significant increase in grain yield at most of the years.

Table 3.3. 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	1994
S12203	INGVAR LYCHE, SØNDRE ØSTFOLD FSR					
	BARLEY	OAT	WHEAT	BARLEY	OAT	OAT
N 6	329b	514c	412c	193b	428a	361c
N10	378a	560b	480b	177c	368b	401b
N14	387a	574a	519a	211a	348b	425a
P 0	357a	540b	462b	196a	376ab	391a
P 1	368a	545b	479a	198a	402a	396a
P 3	368a	563a	471ab	187a	367b	398a
S12225	GJERMUNDNES LBS. RAUMA - VESTNES FSR					
		GR.FORAGE	BARLEY	BARLEY	BARLEY	BARLEY
N 2*		304a	352c	286c	196c	149b
N 6*		346a	477b	394b	281b	203a
N10*		337a	515a	464a	376a	189a
P 0		329a	446a	379a	262b	177a
P 1		329a	445a	384a	288a	178a
P 3		328a	453a	381a	302a	186a

* 6 - 10 - 14 kg N daa^{-1} i 1994

In grasses application of superphosphate has resulted in significant increase in dry matter yield at Jæren site in 1991, 92 and 94, at Nesset site in 1992, 93 and 94 and at Lofoten and M.- Agder sites in 1994 (Table 3.4). Positive crop yield response by superphosphate has been observed in many years at most of the other sites.

Table 3.4 (continues)

S12213 JOHN HANSEN, LOFOTEN FSR

GRASS	-	2 cuts	2 cuts	2 cuts	2 cuts	2 cuts
N 8+4		1045a	861a	605a	662a	696ab
N12+8		1045a	848a	626a	752a	627b
N16+12		1046a	858a	593a	717a	793a
P 0		997a	838a	590a	695a	614b
P 1		1065a	849a	588a	709a	750a
P 3		1074a	881a	645a	726a	752a

S12214 MIKAL GODTFREDSEN, MIDT-AGDER FSR

GRASS	2 cuts	2 cuts	2 cuts	2 cuts	2 cuts	2 cuts
N 8+4	989	1033a	749a	607ab	820a	710a
N12+8	995	997a	730a	625a	861a	687a
N16+12	975	1005a	729a	578b	851a	687a
P 0	1000	1002a	722a	598a	816a	656b
P 1	974	1010a	738a	602a	854a	709ab
P 3	985	1023a	747a	610a	862a	719a

S12217 ODD Å. FAGERENG, VESTERÅLEN FSR

GRASS	1 cut	2 cuts	2 cuts	2 cuts	2 cuts	2 cuts
N8(+4)	247b	957a	874b	726b	679a	704c
N12(+8)	295b	988a	937a	750ab	744a	813b
N16(+12)	364a	1019a	933a	781a	758a	881a
P 0	310a	1018a	906a	747a	747a	791a
P 1	283a	977a	912a	747a	705a	791a
P 3	312a	969a	926a	763a	730a	815a

Concentration and Uptake of N and P in 1993 and 1994.

Concentration and uptake of P in grain yield were not affected by application of superphosphate in means of the three N levels (Tables 3.5 and 3.6). Higher N rates resulted in some higher P concentration, a higher grain yield and a higher P uptake in consequence. Higher rates of N resulted also in higher concentration and uptake of P in grasses. Higher rates of N resulted also in higher concentration and uptake of N in grasses, but still there was low recovery of applied extra N (Table 3.10).

Table 3.9. Uptake of P in grass yield as affected by N and P application (kg daa^{-1}). Means of 7 sites 1993 and 6 sites 1994.

	N1	N2	N3	P0	P1	P3
1993	2.36	2.61	2.63	2.43	2.53	2.64
1994	2.26	2.50	2.57	2.29	2.44	2.59

Table 3.10. Concentration and uptake of N in grass yield as affected by N application. Means of 7 sites 93 and 6 sites 94.

	Conc.(g N kg^{-1})			Uptake(kg N daa^{-1})		
	N1	N2	N3	N1	N2	N3
1993, 1.cut	18.9	21.2	23.3	9.53	10.69	11.23
2.cut	21.0	24.1	27.9	5.08	6.57	7.68
1994, 1.cut.	19.7	21.4	22.9	8.02	8.78	9.95
2.cut	21.1	24.3	26.7	5.54	7.42	8.14

Conclusions

Grain yields have increased significantly by application of superphosphate at all sites, but only for one or two years of the research period. Generally, N rates up to the highest level have resulted in significant increase in grain yield at all sites.

P concentration and uptake have not been affected by application of superphosphate in cereals, but higher rates of N resulted in higher P uptake as well as higher uptake and concentration of N.

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

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

In the production of CN with S added different S sources can be used. Therefore, pot trials were laid out in 1993 to test the effect of S sources of currant interest when incorporated in CN. The effect of kieserite and gypsum were found to be excellent and they were somewhat better than elemental S.

The pot trials were continued in 1994 with the same soil as used in experiment II in 1993, a sandy soil mixed with 20 % volumes of peat. The soil was added $CaCO_3$ to get a pH value of about 6.0. 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

Part I:
Test fertilizers mixed into the soil before sowing of ryegrass

Experimental layout

As last year this greenhouse experiment was laid out in pots of 6.7 litres with ryegrass as test plant. All treatments were of nutrients was left in these pots in contrast to the other treatments producing big crops.

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

Treatm.	1.cut	2.cut	3.cut	4.cut	Total
a.(without S)	2.0	1.3	7.5	30.4	41.2c
b.(w/kieser.inc.)	24.6	31.8	26.4	18.4	101.2ab
c.(w/gypsum inc.)	22.5	31.9	29.0	19.8	103.3a
d.(w/elem.S inc.)	27.3	20.6	28.8	19.8	96.5b
e.(kieser.separ.)	26.1	25.8	27.9	19.5	99.3ab
f.(gypsum separ.)	26.3	26.1	27.3	18.5	98.2ab
g.(elem.S separ.)	29.4	25.7	28.9	19.8	103.8a

The effect of elemental S was better this test year and adding separatly the effect was as good as for kieserite and gypsum incorporated in CN. The reason for this could be that some elemental S added last year was change to available form.

This year small differences in crop yield were observed for kieserite and gypsum applied incorporated or separatly. As last year the effect of elemental S was best when it was applied separatly.

Concentration and Uptake of N and S.

Concentration of Kjeldahl N and nitrate N was strongly reduced to a normal level by application of all S sources (Table 4.3). This effect of S application must be due to a higher crop yield and a normal nitrate turnover in the plants. Total uptake of S was increased to the same level by all S sources.

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 I after 1., 2. and 3. cut. Barley being harvested at ripening was not top dressed.

Crop Yield

Total dry matter yield of ryegrass was significantly increased by all S treatments with exception of CN^{18} + kieserite added separatly (Table 4.4). In first cut there was no response in crop yield by use of gypsum incorporated in CN^{18} as well as kieserite added separatly to CN^{18}. Two of three pots in the last mention treatment were in bad condition by some reason. In contrary to part I the effect of elemental S incorporated was as good as for kieserite and gypsum. As last year the effect of kieserite incorporated in CN^{18} was as good as separate application of kieserite to CN (treatm. d and b).

Table 4.4. Effect of different S sources on dry matter yield of ryegrass, g/pot.

Treatm.	1.cut	2.cut	3.cut	4.cut	Total
a. (CN without S)	17.6	5.9	24.5	26.0	74.0b
b. (CN +kies. sep.)	24.3	31.9	27.3	18.2	101.7a
c. (CN^{18} +kies. sep.)	17.2	15.8	28.8	20.5	82.3b
d. (CN^{18}w/kies. inc.)	23.2	33.0	28.8	19.7	104.6a
e. (CN^{18}w/gyps. inc.)	19.0	32.8	30.0	20.1	101.9a
f. (CN^{18}w/el. S inc.)	22.5	26.2	28.9	19.5	97.2a

Grain and straw yields of barley were increased by all S treatments, but gypsum incorporated in CN^{18} resulted in lesser yield than kieserite and elemental S (Table 4.5). No significant difference in crop yield was observed between kieserite added separatly to CN^{18} respectively CN.

Table 4.7. 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.	2.53	564	0.010	2.2	0.10	22
b.	1.53	708	<0.005	2.5	0.11	50
c.	1.49	795	<0.005	2,9	0.11	58
d.	1.54	742	0.011	5.3	0.11	53
e.	1.70	665	<0.005	2.1	0.12	47
f.	1.64	776	<0.005	2.6	0.12	57
			Straw			
a.	1.18	273	<0.005	1.2	0.07	15
b.	0.41	147	0.009	3.0	0.09	31
c.	0.38	151	<0.005	2.1	0.10	39
d.	0.39	136	<0.005	1.8	0.10	36
e.	0.42	117	<0.005	1.5	0.09	24
f.	0.41	153	<0.005	2.0	0.08	31

TEST RESULTS IN MEAN OF 2 YEARS.

Part I

Total crop yield in ryegrass has been highly increased by all S treatments (Table 4.8). Kieserite and gypsum incorporated resulted in significantly higher crop yield than all other S treatments. The effect of elemental S incorporated has been lesser than added separatly to CN_{18}.

Table 4.8 Effect of different S sources on dry matter yield of ryegrass, g/pot, in mean of 2 years.

Treatm.	1.cut	2.cut	3.cut	4.cut	Total
a.(without S)	3.8	1.5	4.1	15.2	24.6d
b.(w/kieser.inc.)	28.1	30.7	20.1	11.3	90.3a
c.(w/gypsum inc.)	26.5	30.9	21.3	12.5	91.2a
d.(w/elem.S inc.)	29.5	18.5	18.1	11.1	77.3c
e.(kieser.separ.)	28.2	26.9	20.4	11.3	86.9b
f.(gypsum separ.)	29.1	26.8	19.7	10.8	86.5b
g.(elem.S separ.)	29.1	26.0	19.2	11.3	85.6b

Table 4.10. Effect of different S sources on grain and straw yields of barley, g/pot, in means of 2 years.

Treatm.	Grain	Straw
a. (CN without S)	23.4c	22.2c
b. (CN + kies. sep.)	39.6ab	30.7ab
c. (CN^{18} + kies. sep.)	43.7a	33.4a
d. (CN^{18} w/kies. inc.)	40.5ab	30.9ab
e. (CN^{18} w/gyps. inc.)	36.5b	27.9b
f. (CN^{18} w/el. S inc.)	41.4ab	32.2a

Recovery of S and N/S ratio.

The recovery of S has been very high in these experiments. When roots are included all S applied to ryegrass through incorporated kieserite and gypsum in part I must have been taken up. In part II uptake of S through ryegrass has been even higher than in part I but extra S is applied before sowing. Approximately 50% of S applied has been taken up in barley.

S deficiency can be indicated by crop analysis. If N:S ratio is greater than 16:1 yield response will probably be found. In this experiment N:S ratio was much higher without application of S. N:S ratio was far below 16:1 when S was applicated with exceptions of elemental S incorporated in CN_{18} in part I and treatment c in part II with two pots in bad conditions last year.

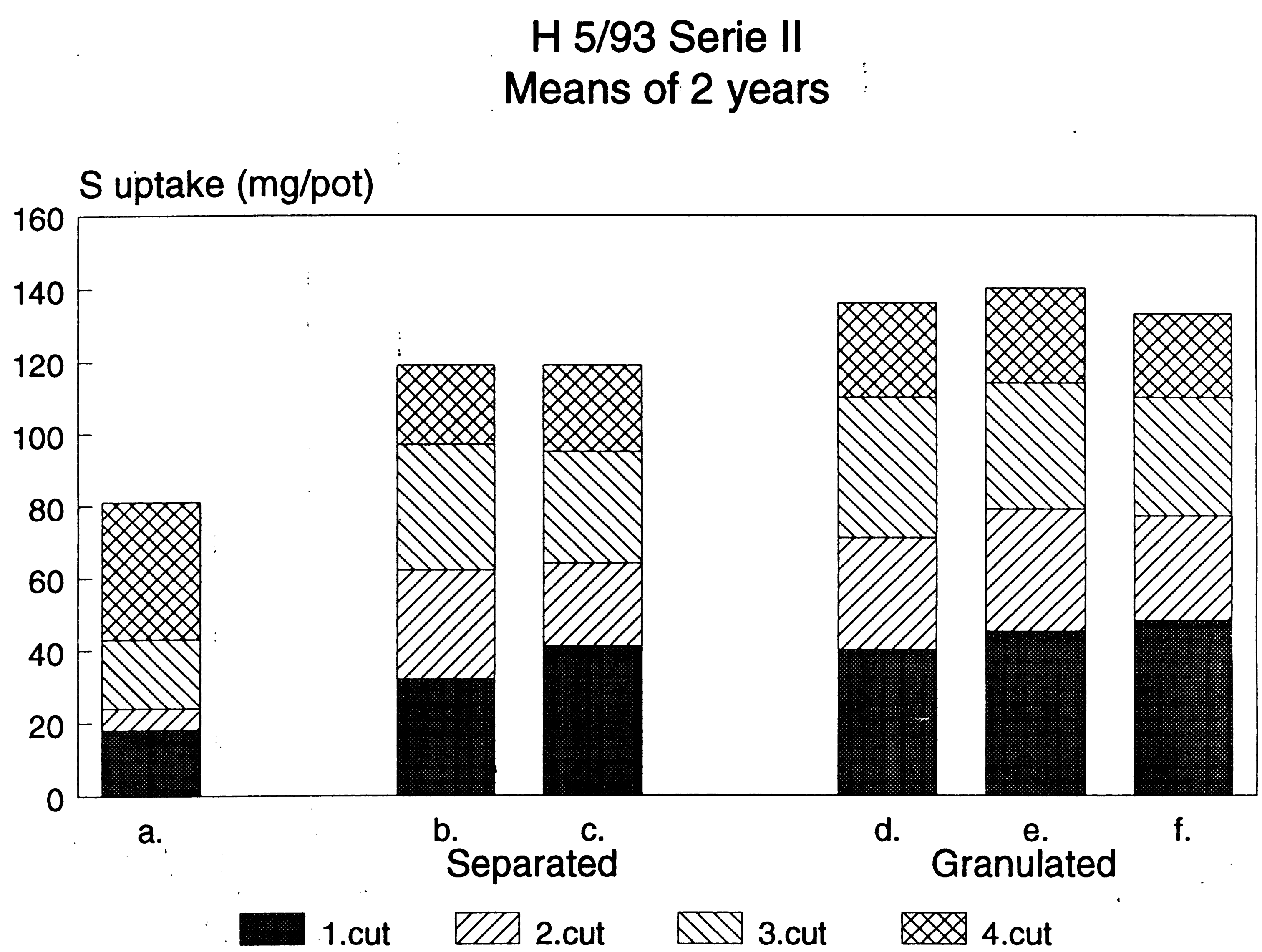

Fig.4.2. S uptake in Ryegrass

Conclusions

In two years experiments ryegrass and barley yields have increased strongly by application of S irrespective of its source.

Kieserite and gypsum incorporated in CN_{18} resulted in significantly higher ryegrass yield than elemental S and when the S sources were applied separatly.

There was no difference in ryegrass yield between the S sources when they were applied separatly but the effect of elemental S was relatively better than incorporated in CN^{18}.

Gypsum resulted in lesser crop yield than kieserite and elemental S in barley.

The effect of CN_{18} with kieserite incorporated was as good as CN + kieserite applied separate in ryegrass as well as barley.

Uptake of S in crop yield increased very much by all S sources applied. The rate of increase was in the order kieserite = gypsum > elemental S in ryegrass and kieserite > elemental S > gypsum in barley.

Uptake of S in ryegrass was highest when kieserite and gypsum were incorporated in fertilizer.

S application resulted in a strong reduction in concentration of nitrate in dry matter of ryegrass.

N/S ratio expressed in g kg^{-1} dry matter was very high without and with only little S applied being reduced to normal level by application of S to ryegrass as well as barley.

Ryegrass was harvested 4 times during the growing season. K through KCl was top dressed at the rate of 9 kg/daa after 1. and 2.cut and at the rate of 6 kg/daa after 3.cut. The moisture content in the pots was maintained by regular watering with deionized water.

Table 5.1. Nutrient applied to each cut(* through the treatments, kg/daa.

Treatments	N	Mg	Ca	S
a. Calsium Nitrate (CN)	8	-	9.8	-
b. HYDRO-KAS™	8	0.6	1.2	-
c. CN w/kieserite incorp.	8	1.3	9.8	1.4
d. CN w/kies.incorp.+sep.	8	2.2	9.8	2.1
e. HYDRO SVOVELPLUSS™	8	0.4	0.6	2.1

(* After 3. cut applied nutrients was 75 % of the other three dressings.

Crop Yield.

There was a high crop yield level in this pot experiment but no effect of S application through N-fertilizers (Table 5.2). When N-level was increased by ammonium-nitrate a small but significantly increase in crop yield was observed. Still the lacking effect of S or the relation between the treatments were not affected.

Table 5.2. Effect of S-enriched N-fertilizers on dry matter yield of ryegrass in mean of 2 N-levels, g/pot.

Treatments	1.cut	2.cut	3.cut	4.cut	Total
a. CN	16.2a	20.6a	19.0a	15.3a	71.1a
b. HYDRO-KAS™	16.1a	19.3c	17.7c	13.1c	66.1b
c. CN w/kies.inc.	16.3a	20.0abc	19.2a	14.8ab	70.3a
d. CN w/kie.inc+sep	16.3a	20.2ab	19.5a	14.2b	70.2a
e. HYDRO S-PLUSS™	16.1a	19.6bc	18.2b	12.9c	66.8b

The main difference between the treatments is the significant higher crop yield by use of CN compared with the two other nitrogen fertilizers (treatment b and e). Reasons for this

Total uptake of N, K and Ca in crop yield was highest in treatments with CN (Table 5.5). When kieserite was added to CN total uptake of S and Mg also was highest in these treatments. There was a very high recovery of all nutrients added through all CN treatments.

Table 5.5. Effect of treatments on uptake (mg/pot) of Kjeldahl N, total S, K, Ca and Mg in ryegrass. Sum of 4 harvests and average of 2 N levels.

	Kjeldahl N	Total S	K	Ca	Mg
a	1241a	131cb	1725a	668a	88b
b	1129c	119c	1478b	487b	97b
c	1248a	149ab	1720a	642a	135a
d	1266a	164a	1745a	622a	154a
e	1176b	145ab	1489b	427b	92b

Discussion

The lack of response for S in this pot experiment was surprising because heavy S deficiency is observed in former tests in this soil growing ryegrass. The soil analyses of total S also indicate small amounts of S available for a ordinary crop yield. Could some extra S have been released from the soil because of a very high temperature in the greenhouse this summer? The basal dressing of 0.9 kg S pr daa in NPK 17-5-13 are corresponding well to the S taken away by the first harvest.

6. EFFECT OF BRUCITE AS A MAGNESIUM-SOURCE.

Brucite consists of about 95% $Mg(OH)_2$ (39% Mg) with water solubility higher than for dolomite. In pot experiments less soluble Mg-sources such as dolomite has been found to have as good residual effect as kieserite. It was therefore decided to evaluate the availability of Mg to plants from brucite in comparison to dolomite and kieserite. This was done in order to evaluate brucite as a potential Mg-source in the NPK-fertilizer production process.

BRUCITE AS A MG-SOURCE TO OAT AND RYEGRASS.

In 1993 a pot experiment was started up using a Mg-poor sandy soil collected from Elverum as a test soil. Some selected properties of the soil are presented in table 6.1. In oat as well as ryegrass crop yield and Mg-uptake were increased by all Mg-sources, but the effect of kieserite and brucite was better than of dolomite. This experiment was continued in 1994 using the same test soil.

Table 6.1. Selected properties of the soil used

	pH	*	P-AL	K-AL	Mg-AL	Ca-AL
Sand	5.6	0.3	2.3	<1.0	1.1	8.4

* loss on ignition

The test was done in oat and ryegrass at soil pH levels 5.5 and 6.5 in 1993 as well as in 1994.

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

Treatm.	Grain pH 5,5	Grain pH 6,5	Grain Mean	Straw pH 5,5	Straw pH 6,5	Straw Mean
a.	5.1	10.9	8.0 f	15.0	22.7	18.8 c
b.	40.0	36,4	38.2 a	31.0	32.1	31.6 a
c.	14.5	18.9	16.7 e	23.9	30.5	27.2 b
d.	37.1	33.6	35.4 bc	30.5	30.8	30.7 a
e.	37.6	36.4	37.0 ab	31.1	33.4	32.2 a
f.	35.5	29.6	32.5 d	31.7	31.0	31.4 a
g.	34.1	35.5	34.8 c	30.1	31.5	30.8 a
Mean	29.1 a	28.7 a		27.6 b	30.3 a	

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

The dry matter yield of ryegrass was significantly increased by all Mg-sources applied incorporated as well as separately (Table 6.3). This year the effect of all Mg-sources was better when they were applied separately. The effect of dolomite was not as good as the effect of the other two Mg-sources when they were incorporated in the fertilizer. There was no difference in ryegrass yield response between brucite and kieserite.

Table 6.3 Effect of different Mg sources on dry matter yield of ryegrass, g/pot, sum of 4 harvests.

Treatments	pH 5,5	pH 6,5	Mean
a. NP without Mg	60.2	66.5	63.4 d
b. NP w/brucite	96.4	91.4	93.9 b
c. NP w/dolomite	91.3	82.1	86.7 c
d. NP w/kieserite	94.0	92.7	93.4 b
e. NP,brucite separ.	97.1	98.9	98.0 a
f. NP,dolomite separ.	97.6	94.0	95.8 ab
g. NP,kieserite separ.	96.7	99.4	98.0 a
Mean	90.5 a	89.3 a	

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

separatly than by dolomite incorporated in NP. On the other hand dolomite incorporated resulted in higher concentration and uptake of Ca than the other Mg treatments.

There was no influence of pH on relations between the Mg-sources regarding effect on Mg concentration or uptake of Mg, Ca and K in crop yield.

Table 6.5. Effect of method of application and sources of Mg on content and uptake of Mg, Ca and K in ryegrass. Average and sum of 4 harvests for the concentration(%) and uptake(mg/pot), respectively.

	Mg		Ca		K	
	Conc.	Uptake	Conc.	Uptake	Conc.	Uptake
NP without Mg	0,082	52	1,20	761	4,45	2810
NP w/brucite	0,117	110	0,81	758	2,84	2670
NP w/dolomite	0,083	73	1,03	891	3,15	2730
NP w/kieserite	0,124	116	0,74	693	2,80	2620
NP,brucite sep.	0,104	102	0,79	778	2,68	2630
NP,dolom. sep.	0,086	82	0,85	814	2,66	2550
NP,kieser. sep.	0,119	116	0,76	744	2,75	2690

Test Results in Mean of Two Years

Crop Yield in Oat and Ryegrass

Crop yield in oat as well as ryegrass has been highly increased by Mg application (Tables 6.6 and 6.7). Brucite and kieserite increased crop yield much more than dolomite with the exception of separate application at low pH. The effect of dolomite allways was better applied separatly compared with incorporated in NP. The effect of kieserite on crop yield has been little influenced by the application method while the effect of brucite applied separatly was somewhat better in ryegrass but not in oat. The effect relations between kieserite and brucite was little inluenced by soil pH.

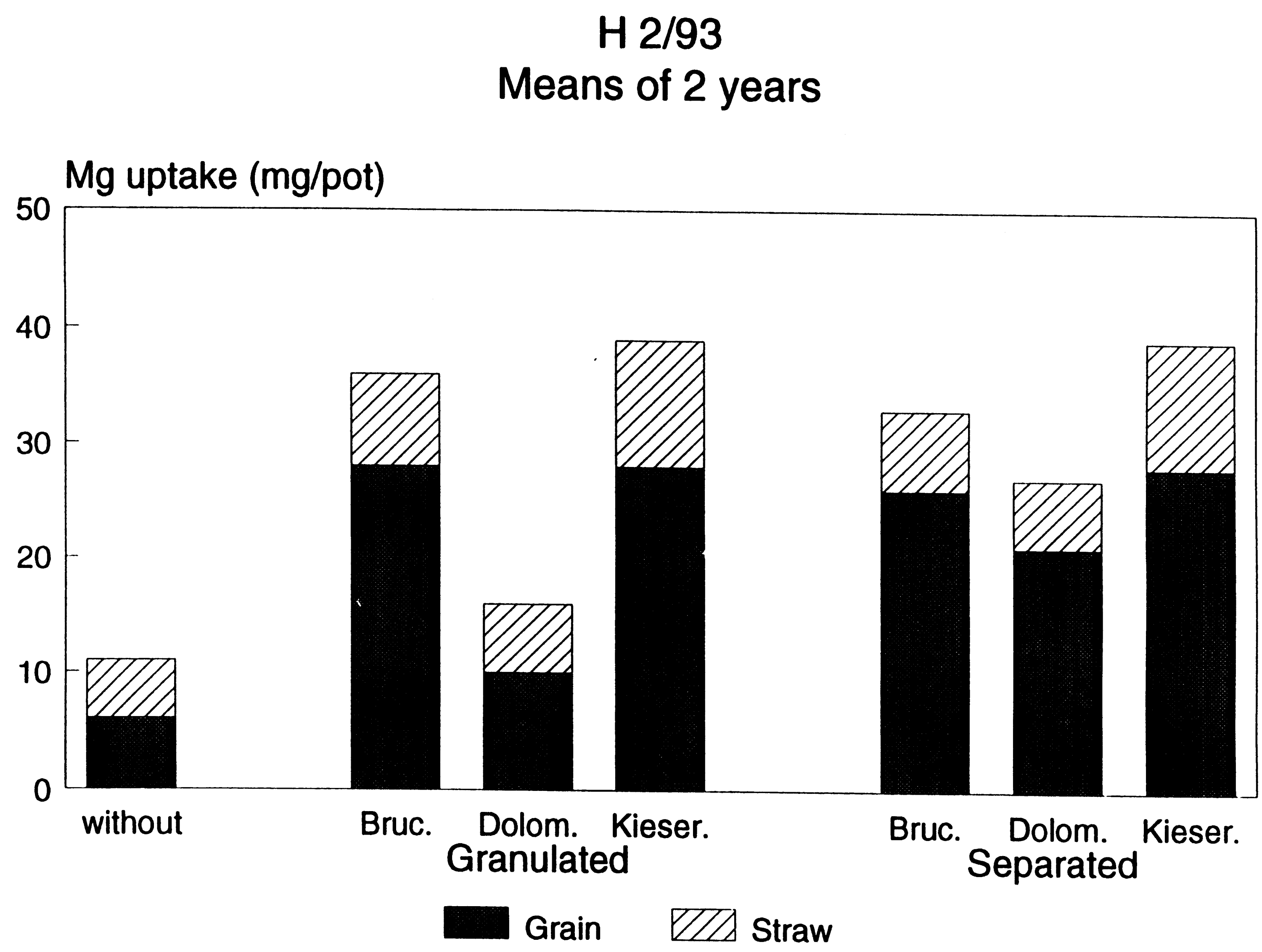

Fig. 6.1. Mg Uptake in Grain and Straw of Oats

The recovery of Mg in crop yield as part of Mg applied in mean of all research parameters and two years has been very high for kieserite and brucite; respectively 58% and 48% in oat and 100% and 80% in ryegrass. Corresponding values for dolomite were 22% and 38% in oat respectively ryegrass but the recovery of Mg in dolomite was higher when applied separately.

Conclusions

Crop yield of oat and ryegrass increased significantly by 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.

Concentration and uptake of Mg in crop yield of oat as well as ryegrass generally increased by Mg application and the rate of increase was in the order kieserite > brucite > dolomite.

The effect of kieserite on Mg uptake was not affected by the application method but brucite resulted in somewhat higher Mg uptake incorporated in NP. Dolomite was relatively more effectiv in increasing Mg uptake applied separately than incorporated in NP.

Crop Yield

Dry matter yield of lettuce was significantly increased by brucite and kieserite incorporated in NP-fertilizer (Table 6.8). Dolomite had no effect on crop yield. The growth of lettuce was better but not optimal at the highest pH level. pH level was grately affected by the treatments during the growth period. CEC is very low in the test soil. The pH values after harvest were least reduced by NP-fertilizer with brucite and most reduced by NP-fertilizer without Mg (Table 6.9).

Table 6.8. Effect of Mg sources on dry matter yield of lettuce, g pot^{-1}.

Treatm.	pH 6	pH7	Mean
a.	4.0	7.5	5.8b
b.	7.6	9.9	8.7a
c.	4.0	6.9	5.5b
d.	7.0	9.7	8.4a
Mean	5.7b	8.5a	

Table 6.9. pH in test soil after harvest of lettuce.

	pH 6.0				pH 7.0			
Treatments:	a	b	c	d	a	b	c	d
pH harvest:	5.5	5.8	5.6	5.6	5.4	6.1	5.6	6.0

Concentration and Uptake of Mg, Ca and K in Crop Yield.

NP-fertilizer with kieserite or brucite incorporated increased concentration and uptake of Mg and uptake of Ca and K in crop yield (Table 6.10). These parameters were not influenced by dolomite incorporated in NP at all. The highest pH level resulted in increased concentration and uptake of Ca and uptake of Mg and K in crop yield.

7. EFFECT OF MANGANESE (Mn) INCORPORATED IN NPK-FERTILIZER.

Manganese is an essensiell micronutrient for plants and animals. Usually most soils have enough Mn but Mn is disposed to be tied up in heavily available Mn-oxids. The availibility of Mn in soil is reduced by high soil pH and high content of oxygen in soil.

Mn deficiencies are common in field crops in many countries, and in UK and Denmark big agricultural areas are exposed for this problem. Usually Mn deficiencies are cured by Mn spraying of plants. This gives an effectiv uptake of Mn in plants, but at this moment plants already can have been exposed for demage. Spraying with Mn gives also an extra operational cost. If Mn could be added to NPK fertilizers Mn deficiencies could be prevented. Still the problem is that Mn incorporated in NPK can be tied up very fast in the soil. Granulated fertilizer and drill fertilizing reduce the soil contact and this could increase the availibility of Mn to plants.

POT EXPERIMENT I

In 1993 a pot experiment was started up to test the effect of Mn incorporated in an NPK fertilizer. Mn-sulphate was used as Mn-source equivalent to 0.6 % and 1.2 % Mn incorporated in NPK 22-2-12. A Mn-poor sandy soil mixed with 20 vol.% sphagnum peat was used as growth medium. Still, there was optimal growth at the control plots and no effect of applied Mn on crop yield. However, concentration and uptake of Mn in crop yield were increased by all Mn treatments.

In 1994 this pot experiment was continued with the same soil but the treatments were reduced to one Mn rate and one application method only. Some selected properties of the soil components are presented in table 7.1. The two pH levels of the mixed soil was again adjusted with lime.

lowest pH level (Table 7.2). There was no sign of Mn deficiences on oat plants in the growing season.

Table 7.2. Effect of Mn-enriched NPK on grain and straw yields of oat (g/pot) grown at two pH levels.

Treatm.	Grain			Straw		
	pH 6	pH 7.5	Mean	pH 6	pH 7.5	Mean
a.	50.3	47.5	48.9a	48.8	46.3	47.6a
b.	50.5	47.2	48.9a	48.0	46.9	47.4a
c.	50.9	48.6	49.8a	49.2	47.5	48.3a
Mean	50.6a	47.8b		48.7a	46.9a	

Manganese Concentration and Uptake

Concentration and uptake of Mn in grain and straw were increased by Mn applications at the lowest soil pH level only (Table 7.3). At this pH the increase in Mn uptake was representing about 50% of Mn added in fertilizers. There was little difference in influence of Mn incorporated in NPK and Mn applied separately. When soil pH was increased to 7.5 concentration and uptake of Mn were tremendously reduced at all treatments.

Table 7.3. Effect of Mn-enriched NPK on concentration and uptake of Mn in oat grown at two pH levels.

Treat-ment	Grain			Straw		
	pH 6	pH 7.5	Mean	pH 6	pH 7.5	Mean
			Concentration (mg kg^{-1})			
a.	108	33	71a	180	14	97a
b.	151	38	95a	349	15	182a
c.	162	26	94a	412	7	210a
Mean	141a	32b		314a	12a	
			Uptake (mg pot^{-1})			
a.	5.4	1.6	3.5a	8.8	0.6	4.7a
b.	7.6	1.8	4.7a	16.7	0.7	8.7a
c.	8.2	1.3	4.8a	20.3	0.4	10.3a
Mean	7.1a	1.5b		15.3a	0.6a	

Manganese Concentration and Uptake

Mn concentration and uptake in grain and straw were increased by application of Mn-enriched NPK as well as Mn-sulphate separately (Table 7.5). The increase in Mn uptake was representing 20% of Mn added through the fertilizers.

Table 7.5. Effect of Mn-enriched NPK on concentration and uptake of Mn in oat.

Treat-ment	Concentration, mg kg^{-1}		Uptake, mg pot^{-1}		
	Grain	Straw	Grain	Straw	Total
a.	118	194	3.4	6.3	9.6
b.	150	291	4.4	9.9	14.2
c.	150	291	4.3	9.8	14.1

Conclusion

Application of Mn resulted in increased concentration and uptake of Mn in grain and straw but it had no effect on crop yield.

POT EXPERIMENT III

In 1994 a new pot experiment was started up in moraine soil from Rygge council. Some properties of the soil are presented in table 7.6. The nutrient condition of the soil is very good but the content of soluble Mn is small at this high soil pH. The test was done with 2 soil pH levels by treating one part of the soil with sulphuric acid.

Table 7.6. Properties of soil used in experiment III.

*	pH	P-AL	K-AL	Mg-AL	Ca-AL	Mn	B	Zn	Mo
		- - -	mg/100gram	- - -		- - -	mg/kg	- - - -	
1.3	7.7	64	26	18	394	0.6	0.5	20.0	0.14

* loss on ignition

Table 7.7. Effect of Mn-enriched NPK on grain and straw yields of oat (g/pot), mean of application methods

Treatm.	Grain pH 6,5	Grain pH 7.7	Grain Mean(pH)	Straw pH 6,5	Straw pH 7.7	Straw Mean(pH)
a.	51.9	48.1	50.0b	42.1	42.1	42.1a
b.	51.6	49.4	50.5ab	41.3	41.6	41.5ab
c.	52.6	49.6	51.1a	41.0	40.7	40.8b
d.	51.1	48.7	49.9b	41.7	40.5	41.1b
e.	52.0	47.9	50.0b	42.1	40.8	41.4ab
Mean	51.8a	48.8b		41.6a	41.1a	

Table 7.8. Effect of Mn rates, Mn fertilizers and application methods on grain and straw yields of oat (g/pot)

Rates & methodes	Grain pH 6.5	Grain pH 7.7	Grain Mean	Straw pH 6.5	Straw pH 7.7	Straw Mean
0.6% Mn	51.3	49.1	50.2a	41.5	41.1	41.3a
1.2% Mn	52.3	48.8	50.5a	41.5	40.7	41.1a
Mn incorp.	52.1	49.5	50.8a	41.1	41.2	41.1a
Mn separate	51.5	48.3	49.9b	41.9	40.6	41.3a
Mixed w/soil	51.5	48.8	50.2a	40.6	40.8	40.7b
Band placem.	52.1	49.0	50.5a	42.4	41.0	41.7a

Means with the same letter in the same column or row are not significant different at P= 0.05.

Manganese Concentration and Uptake

Concentration and uptake of Mn in crop yield were increased by all Mn treatments and up to the highest Mn rates (Tables 7.9 and 7.10). Placement of fertilizer resulted in higher concentration and uptake of Mn than fertilizer mixed in to the soil, but there was no difference in effect of added Mn if Mn-sulfat was added separatly or incorporated in NPK.

Concentration and uptake of Mn were strongly reduced at all treatments when soil pH was increased to 7.7, but the effect of Mn added compared to control was about the same. The recovery of added Mn in this experiment was very weak at all Mn treatments.

Conclusions

Grain yield was increased by application of 1.2% Mn incorporated in NPK, but straw yield was highest without Mn added.

Mn concentration and uptake in crop yield were increased by all Mn treatments up to the highest Mn rate at both pH level.

The effect of Mn added was best by band placement of fertilizers but in any case the recovery of Mn was small.

Mn concentration and uptake in crop yield were strongly reduced at the highest pH level.

sites at Ytre Fjordane were continued in 1994, but Fureneset site was established in new on another field.

The main soil chemical properties of the soil collected from five of these sites are presented in Table 8.1.

Table 8.1. Some chemical properties of the soils used

Exp. sites	pH	P-AL	K-AL	Mg-AL	Org.C	Co
1. Særheim, pH I	5.2	24.0	26.0	34.0	6.3	0,09
" pH II	5.6	14.0	11.0	16.0	5.0	0.04
2. Særheim, pH I	5.1	16.0	7.4	9.4	2.5	0.07
" pH II	5.4	16.0	6.6	7.8	2.5	0.04
3. Fureneset	4.7	7.1	19.0	80.0	50.7	0.04
6. Vesterålen	5.5	8.8	11.0	89.0	36.8	0.15
7. Vesterålen	7.6	11.0	1.1	740	3.4	0.03

The analyses show that all locations have low content of Co in the soil indicating possible Co deficienses in the plants. The soil at all sites are in good condition concerning P, K and Mg with the exception of P at location 7. Vesterålen. The high soil pH at this site in Vesterålen is caused by a high content of shell sand in the soil.

Experimental Layout

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

Crop Yield

In 1994 the total dry matter yields of meadow grass were not affected by Co-enriched NPK (Treatm. b, c, d) or Co applied separatly (Treatm. e, f, g). The highest pH level influenced the total dry matter yields positively except at Sør-Salten site (Table 8.2 and 8.3).

Table 8.2. Dry matter yield of meadow grass, kg daa^{-1}, as affected by Co-enriched NPK and Co applied separatly.

	a	b	c	d	e	f	g
1. Særheim	1021a	1039a	1065a	1057a			
2. Særheim	784a	859a	845a	770a			
3. Fureneset	264a	311a	302a	281a			
6. Vesterålen	729a	735a	735a	743a			
7. Vesterålen	819a	777a	815a	759a	783a	763a	808a
8. Sør-Salten	582a	614a	575a	559a			

Table 8.3. Effect of soil pH on dry matter yield of meadow grass.

	pH 5.0	pH 6.0
1. Særheim	1021a	1070a
2. Særheim	801a	829a
3. Fureneset	266a	313a
6. Vesterålen	735a	736a
8. Sør-Salten	601a	564a

Concentration of Cobalt and Copper

Similar to the greenhouse experiment and the former field experiments, Co concentration in grasses increased with increased rate of Co in the fertilizer applied at all sites (Table 8.4). At all sites in 1994 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 at all sites

Table 8.5. Cu concentration in grass as affected by Co- and Cu-enriched NPK, mg kg^{-1}.

	1. harvest		2. harvest		3. harvest	
Treatment	pH 5.0	pH 6.0	pH 5.0	pH 6.0	pH 5.0	pH 6.0
	S132 01 SFL SÆRHEIM					
a	4	3	5	6	6	6
b	4	3	5	6	7	7
c	4	4	6	6	7	6
d	4	3	6	6	6	6
	S132 02 SFL SÆRHEIM					
a	5	5	5	5	8	8
b	5	5	5	5	9	8
c	5	5	6	5	9	8
d	5	5	5	6	7	8
	S132 03 SFL FURENESET					
a	4	3				
b	4	3				
c	4	4				
d	3	4				
	S132 06 VESTERÅLEN					
a	3	3	5	4		
b	3	3	4	4		
c	4	3	4	4		
d	3	2	5	4		
	S132 07 VESTERÅLEN (pH 7.6)					
a	3		4			
b	3		3			
c	4		5			
d	2		3			
e	4		4			
f	3		3			
g	3		4			
	S132 08 SØR-SALTEN					
a	4	3				
b	4	4				
c	4	4				
d	4	4				

location 07 Vesterålen resulted in extremly high concentration of Co in the plants.

This year Co concentration in the plants was generally higher at the lowest pH level at all locations except at Sør-Salten. As last year concentration of Co was not declining in 2. or 3.

- 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.

Treatments:

	After 1. harvest	After 2. harv.	After 3. harv.
a.	PK 7-18 + CN	CN	CN
b.	" + CN w/0.02% Co	CN	CN
c.	" + CN w/0.02% Co	CN w/0.02% Co	CN
d.	" + CN w/0.01% Co	CN w/0.01% Co	CN
e.	NPK 15-4-12 w/0.02% Co	CN	CN
Kg N/daa:	10	8	8

All the treatments were replicated three times in pots containing 6.7 liters of soil. The pots were watered with deionized water immediately after sowing and at a regular time interval through the growth period. Ryegrass was cut 4 times during the experiment. Potassium-chloride equivalent to 9 kg K/daa was added all pots after 2. and 3. harvest 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 influenced by soil pH, but no significant difference between the treatments was observed (Table 9.2).

Table 9.2. Total dry matter yield of ryegrass as affected by the treatments applied at two pH-levels, g/pot.

Treatm.	pH 5.6	pH 6.5	Mean
a.	89.7	95.7	92.7a
b.	89.5	97.3	93.4a
c.	90.6	96.0	93.3a
d.	91.0	94.4	92.7a
e.	89.7	92.9	91.3a
Mean	90.1b	95.3a	

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

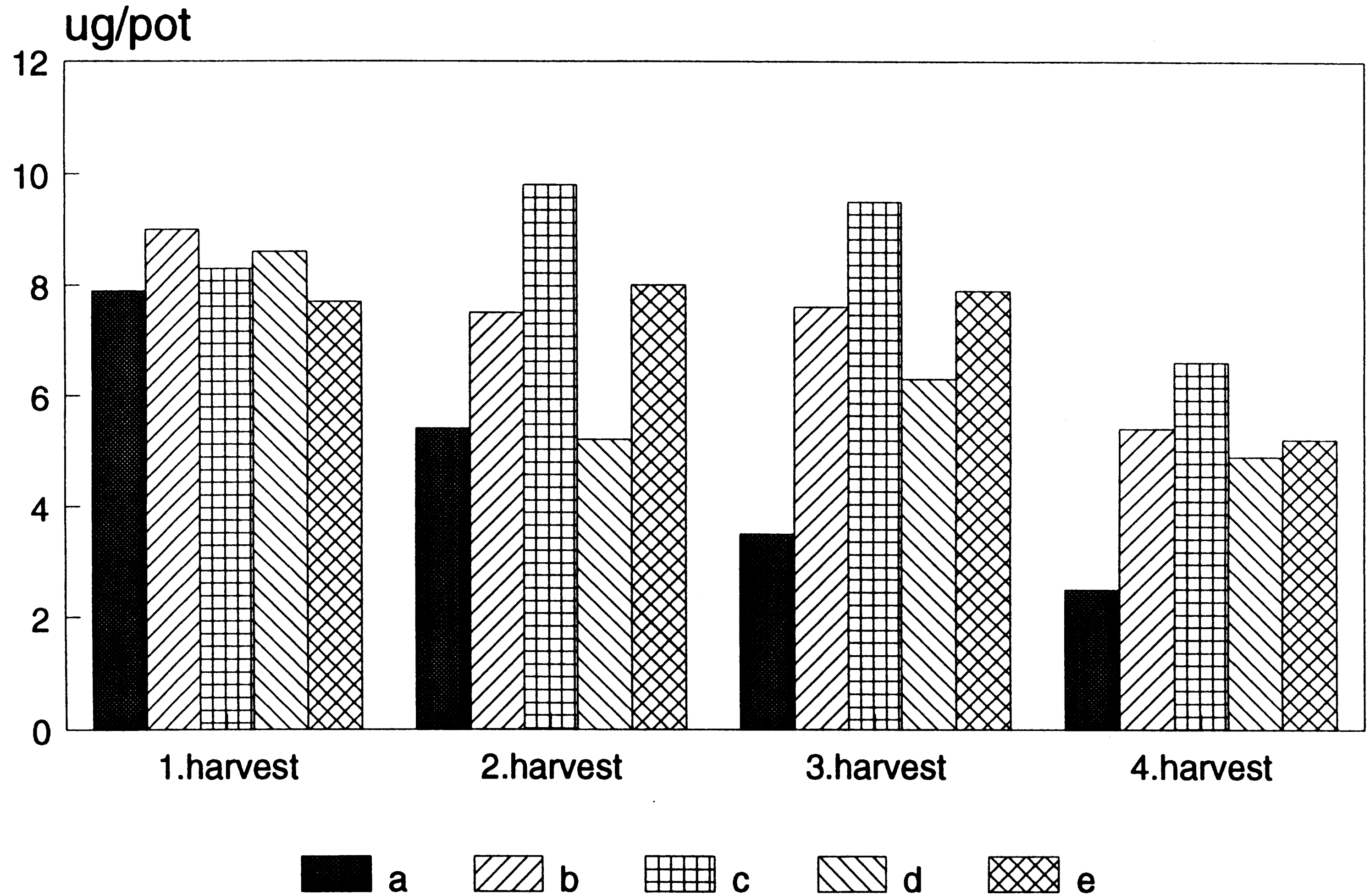

Fig 9.1. Co uptake in ryegrass as affected by Co application through CN and NPK. Mean of 2 pH levels.

FIELD EXPERIMENT

Two field experiments at Særheim Research Station and Fureneset Research Station to supply the tests in greenhouse were started up in 1994. Some chemical properties of the soil at Særheim field are presented in table 9.4. This soil has higher content of organic matter as well as nutrients than the soil from Særheim used in the greenhouse experiment 1994, but the content of Co is on the same low side.

Table 9.4. Some properties of the soil at Særheim site.

pH	*	P-AL	K-AL	Mg-AL	Ca-AL	Na-AL	Cu	Co
		- - - - - mg/100 gram - - - - - -					- mg/kg -	
5.9	15.0	17.0	13.0	19.0	173	5,0	6.9	0.06

* loss on ignition

Experimental Layout.

Treatments:

At spring	After 1. harv.	After 2. harv.
a. PK 7-18 + CN	CN	CN
b. " + CN w/0.02% Co	CN	CN
c. " + CN w/0.02% Co	CN w/0.02% Co	CN
d. " + CN w/0.01% Co	CN w/0.01% Co	CN
e. NPK 15-4-12 w/0.02% Co	CN	CN
Kg N/daa: 10	8	8

pH levels: 5.5 - 6.0 (I) and approxim. 6.5 (II). 500 kg daa^{-1} $CaMgCO_3$ was applicated at Særheim site.

The experiment was laid out in a randomized block design with three replicates. The plot size was 12 m^2 with a harvested area of 9.75 m^2 and 7.5 m^2 at Særheim and Fureneset sites, respectively. The fields are an old pasture dominated by meadow gras and some perennial ryegrass and weeds at Særheim concentration in plants only at Fureneset site, but in 2. and 3. harvests at Særheim this treatment was as effectiv as normal Co quantity applied in spring (treatm. b and e). Normal Co quantity repeated after 1. harvest (treatm. c) resulted in high Co concentration in plants at 2. harvest and desired Co concentration at 3. harvest. Co-enriched NPK showed a trend for some better Co effect than Co-enriched CN.

Table 9.6. Effect of Co-enriched CN on concentration of Co in meadow plants at 2 pH levels at Særheim site.

Treat-ment	1. harvest		2. harvest		3. harvest	
	pH I	pH II	pH I	pH II	pH I	pH II
a.	<0.03	<0.03	<0.03	<0.03	<0.03	0.05
b.	0.05	0.09	0.16	0.10	<0.03	0.04
c.	0.10	0.05	0.36	0.45	0.13	0.12
d.	0.03	0.03	0.14	0.12	0.08	0.06
e.	0.12	0.09	0.15	0.17	0.08	0.04
Mean	0.07	0.06	0.17	0.17	0.07	0.06

Table 9.7. Effect of Co-enriched CN on concentration of K, Ca, Mg and Co in meadow plants at 2 pH levels.

Treat-ment	K, %		Ca, %		Mg, %		Co, mg kg^{-1}	
	pH I	II	pH I	II	pH I	II	pH I	II
Særheim site, mean of 3 harvests:								
a.	2.42	2.68	0.47	0.46	0.21	0.20	0.03	0.04
b.	2.48	2.54	0.51	0.49	0.21	0.22	0.07	0.08
c.	2.25	2.62	0.46	0.51	0.20	0.22	0.17	0.17
d.	2.48	2.49	0.46	0.50	0.21	0.21	0.07	0.06
e.	2.61	2.52	0.44	0.46	0.22	0.24	0.12	0.10
Mean	2.45	2.57	0.47	0.48	0.21	0.22	0.09	0.09
Fureneset site, 1 harvest of ryegrass:								
a.	3.13	2.74	0.42	0.44	0.17	0.15	0.05	0.08
b.	2.87	2.77	0.41	0.44	0.16	0.14	0.25	0.15
c.	2.57	2.99	0.42	0.44	0.16	0.16	0.32	0.12
d.	2.84	3.03	0.41	0.43	0.15	0.16	0.24	0.13
e.	2.94	2.70	0.44	0.42	0.19	0.16	0.33	0.26
Mean	2.87	2.85	0.42	0.44	0.16	0.15	0.24	0.15

Concentration of K, Ca and Mg were little influenced by liming or by the treatments (Table 9.7).

Total uptake of Co in grass yield at Særheim followed the same trend as the concentration (Fig. 9.2).

Conclusions of the Field Experiments

- Co concentration and uptake in plants increased by all Co treatments.

- Liming had little effect on soil pH and Co concentration in plants at Særheim site, but the effect of applied Co was best without liming at Fureneset.

- Co-enriched NPK increased Co concentration and uptake in crop yield some more than Co-enriched CN.

- Repeated Co application after 1. harvest resulted in unessecary high concentration of Co in 2. harvest, but good residual effect in 3. harvest.

- Half rate of Co had good effect in 1. harvest at Fureneset site, but little effect at Særheim site. After repeated application the effect on Co concentration was good in 2. and 3. harvests.