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THE EFFECT OF MAGNESIUM, POTASSIUM AND NITROGEN FERTILIZERS ON THE UPTAKE OF NUTRIENTS BY SPRING CEREALS AND CULTIVATED GRASSLAND

Raili Jokinen

Jokinen, R. 1979. **The effect of magnesium, potassium and nitrogen fertilizers on the uptake of nutrients by spring cereals and cultivated grassland.** Ann. Agric. Fenn. 18: 203—212. (Agrc. Res. Centre, Inst. Agric. Chem. and Phys. SF-31600 Jokioinen, Finland.)

The effect of magnesium fertilizer (57 kg/ha Mg) on the uptake of nutrients by spring cereals and cultivated grasslands was investigated by means of field experiments for two levels of potassium chloride (60 and 240 kg/ha K) and two levels of nitro-chalk (50 and 100 kg/ha N). The fertilizers were applied annually at the start of the growing season over an experimental period of five years. Cereal was grown in the first two years of the experiments, grass in the third and fourth years and cereal again in the fifth year. Six of the seven experiments were conducted on soil with a magnesium content of less than 100 mg/l.

Without the use of magnesium fertilizers an annual average of 3,4 kg/ha of magnesium was extracted from the soil by the grain. The grain took up 0,3 kg/ha (0,5 %) annually of magnesium given in the form of fertilizer.

The hay and aftergrowth from cultivated grassland took up an average of 6,1 kg/ha of magnesium per year when magnesium fertilizer was not used. This figure increased with 2,1 kg/ha per year when 57 kg/ha of magnesium was applied in the form of fertilizer. The grassland crops took up 3,7 % of the magnesium applied as fertilizer.

The apparent recovery of the magnesium applied annually during the five year experimental period varied from one site to another between 1,0 and 8,9 kg/ha (0,4—3 %). The average recovery in the crop rotation studied here was 4,6 kg/ha (1,6 %). The residual effect of magnesium fertilizer was not studied.

Index words: Magnesium, calcium, potassium uptake.

INTRODUCTION

In terms of fodder quality, keeping the potassium content of grassland crops low is more important than replacing the amounts of potassium taken up by the crops with fertilizer (Tähtinen 1979). Grass species may take up more potassium and nitrogen than is given in the form of fertilizer and this leads to depletion of the soil's nutrient reserves (Sillanpää and Rinne 1975, Håland 1976, Tähtinen 1979). The amounts of potassium lost along with the crops may not give the right idea of the need for potassium fertilizer since plants have a tendency to take up more potassium than they actually need.

Magnesium fertilizer raises the magnesium content of the vegetative parts of plants and hence improves the quality of the crop (Håland 1971, Baerug 1977, Jokinen 1977 a, 1979). The over consumption of magnesium is, however, probably rare. The amounts of magnesium lost along with the crops may give some clue to the minimum amount which must be applied as fertilizer. Some studies report that plants take up less than 10 % of the magnesium given as fertilizer (Håland 1971, Jokinen 1977 a, Jaakkola and Vogt 1978). Leaching of magnesium from the soil, the retention of magnesium in the soil and the antagonism between magnesium and other nutrients all make it more difficult for the plants to take up magnesium and increase the need for fertilizer. The abundance of magnesium in the soil, on the other hand, reduces the need for fertilizer.

The aim of this study is to investigate the effect of magnesium, potassium and nitrogen fertilizers, applied annually, on the uptake of nutrients into the grain of spring cereals and by cultivated grassland crops. This study is also examining the effect of potassium and nitrogen fertilizers on the apparent recovery of magnesium applied in the form of fertilizer. The five-year study was carried out by means of field tests on soils containing less than 100 mg/l of magnesium. The use of magnesium fertilizer is probably necessary on these soils for the intensive cultivation of grassland.

MATERIAL AND METHODS

The effect of magnesium sulphate fertilizer (Mg = 57 kg/ha Mg) on the uptake of nutrients into the grain of spring cereals (barley and oats) and by the hay and aftergrowth crops from cultivated grasslands was studied by means of field experiments using two levels of potassium choliride fertilizer ($K_1 = 60$ or $K_4 = 240$ kg/ha K) and two levels of nitro-chalk ($N_1 = 50$ or $N_2 = 100$ kg/ha N). All the fertilizers were applied once annually, at the start of the growing season. The experiments were carried out on sites where the acid ammonium acetate-extractable magnesium content of the plough layer was less than 100 mg/l of soil. Cereals were cultivated during the first two years of the five-year experimental period, grass during years three and four and cereal again in the fifth year. The dominant species of grass was timothy. Detailed information on the yields obtained in the experiments, the changes in the nutrient state of the soil (Jokinen 1978) and changes in the crop nutrient contents (Jokinen 1979) have been published earlier (summarized in Table 1).

The amounts of nutrients removed from the soil along with the crop are calculated as the product of the dry matter yield and its nutrient content. The uptake of nutrients by cereals was investigated for the grain yield only — the straw was ploughed back into the soil without weighing. The uptake of nutrients by grassland crops is calculated separately for the crop harvested as dry hay and for the aftergrowth, and as the total amounts of nutrients taken up by each crop.

The results are tested using the same methods as those employed in the previous parts of this study. The least significant difference ($LSD_{5\%}$) between the potassium levels and the difference between the nitrogen and magnesium treatments for one level of potassium (Cochran and Cox 1966) are presented separately in the tables. Linear correlation analysis has been used to test the correlations between the parameters.

Table 1. The average dry matter yields (kg/ha) of cereals and grasslands, as well as the nutrient contents (mg/g of dry matter) of the yields obtained with experimental treatments. (Mg = 57 kg/ha Mg, N_1 = 50 and N_2 = 100 kg/ha N, K_1 = 60 and K_4 = 240 kg/ha K).

	K_1				K_4			
	N_1	N_1Mg	N_2	N_2Mg	N_1	N_1Mg	N_2	N_2Mg
Cereal								
Yield kg/ha	2 940	2 970	3 050	3 140	2 900	2 960	2 940	2 990
Mg mg/g	1,11	1,15	1,10	1,17	1,12	1,16	1,10	1,15
Ca »	0,56	0,52	0,57	0,53	0,51	0,49	0,54	0,52
K »	4,8	4,8	4,8	4,8	5,0	4,9	4,9	4,7
Dry hay								
Yield kg/ha	5 860	5 820	6 600	6 350	5 620	5 880	6 330	6 630
Mg mg/g	0,76	1,08	0,90	1,17	0,73	0,99	0,80	1,06
Ca »	2,96	2,61	3,30	2,89	2,80	2,48	3,18	2,74
K »	24,6	25,3	27,2	25,6	27,9	27,6	31,3	30,2
Aftergrowth								
Yield kg/ha	1 240	1 160	1 980	1 990	1 010	1 050	1 830	1 930
Mg mg/g	1,13	1,64	0,96	1,35	0,95	1,42	0,96	1,07
Ca »	5,68	5,53	4,14	4,38	5,08	4,82	5,03	3,58
K »	22,8	22,2	23,3	21,2	23,6	23,2	23,2	22,4

RESULTS

Magnesium uptake

The amount of magnesium removed along with the grain was clearly dependent on the yield (r = 0,850**). The magnesium content of the grain was of little significance (r = 0,226*).

The amount of magnesium taken up by the grass harvested as dry hay was proportional to both the dry matter yield (r = 0,632**) and the magnesium content of the crop (r = 0,695**). The uptake of magnesium by the aftergrowth was more clearly correlated with the dry matter yield (r = 0,585**) than with the magnesium content of the crop (r = 0,377**). Of the properties of the soil, only an increase in magnesium content produced a significant increase in the uptake magnesium by both the hay crop (r = 0,513**) and the aftergrowth (r = 0,315**).

Of the treatments used in this study, only magnesium fertilizer significantly increased the amount of magnesium taken up by the grain of spring cereals (0,3 kg/ha/a 9 %, Table 2). There was only a small difference between the amount of magnesium taken up by barley and that taken up by oats. The effect of magnesium fertilizer on the uptake of magnesium by these two cereals was as follows:

Table 2. The magnesium amounts (Mg kg/ha/a) taken up by the cereal and grass crops, a = mean, b = standard deviation, c = range. (Explanations of the symbols in the table 1.)

	K_1				K_4				$LSD_{5}\%$	
	N_1	N_1Mg	N_2	N_2Mg	N_1	N_1Mg	N_2	N_2Mg	K-levels	N-, Mg-treatments
Grain										
a	3,4	3,6	3,5	3,9	3,4	3,6	3,4	3,7	0,11	0,24
b	±1,2	±1,2	±1,2	±1,3	±1,3	+1,2	±1,2	±1,3		
c	1,2—6,0	1,5—6,4	1,5—6,2	1,9—6,5	1,3—6,7	1,5—6,2	1,5—5,9	1,8—6,3		
Hay and aftergrowth										
a	5,6	7,8	7,5	9,6	4,8	6,9	6,5	8,6	0,71	0,72
b	±2,5	±2,9	±2,7	±3,3	±1,8	±2,5	±2,6	±2,3		
c	3,3—12,3	5,3—14,3	4,0—13,1	6,5—13,8	3,9—9,8	4,2—13,2	3,9—13,8	8,4—12,9		

	Mg kg/ha/a Mg_0	Mg_1
Barley (n = 9)	3,3	3,6
Oats (n = 13)	3,6	3,8

The hay and aftergrowth crops were found to have the following annual uptakes of magnesium (kg/ha):

	Hay crop	Aftergrowth	Total
Mg_0	4,6	1,5	6,1
Mg_1	6,2	2,0	8,2

The increase in the uptake of magnesium (2,1 kg/ha/a, 24 %) brought about by the use of magnesium fertilizer was statistically significant. With the higher level of nitrogen fertilizer the uptake of magnesium was 1,8 kg/ha/a (6,3—8,1 kg/ha/a, 9 %) higher than with the smaller amount of nitrogen fertilizer. The crops took up the following amounts of magnesium for the two nitrogen levels:

	Mg kg/ha/a Mg_0	Mg_1
N_1	5,2	7,3
N_2	7,0	9,1

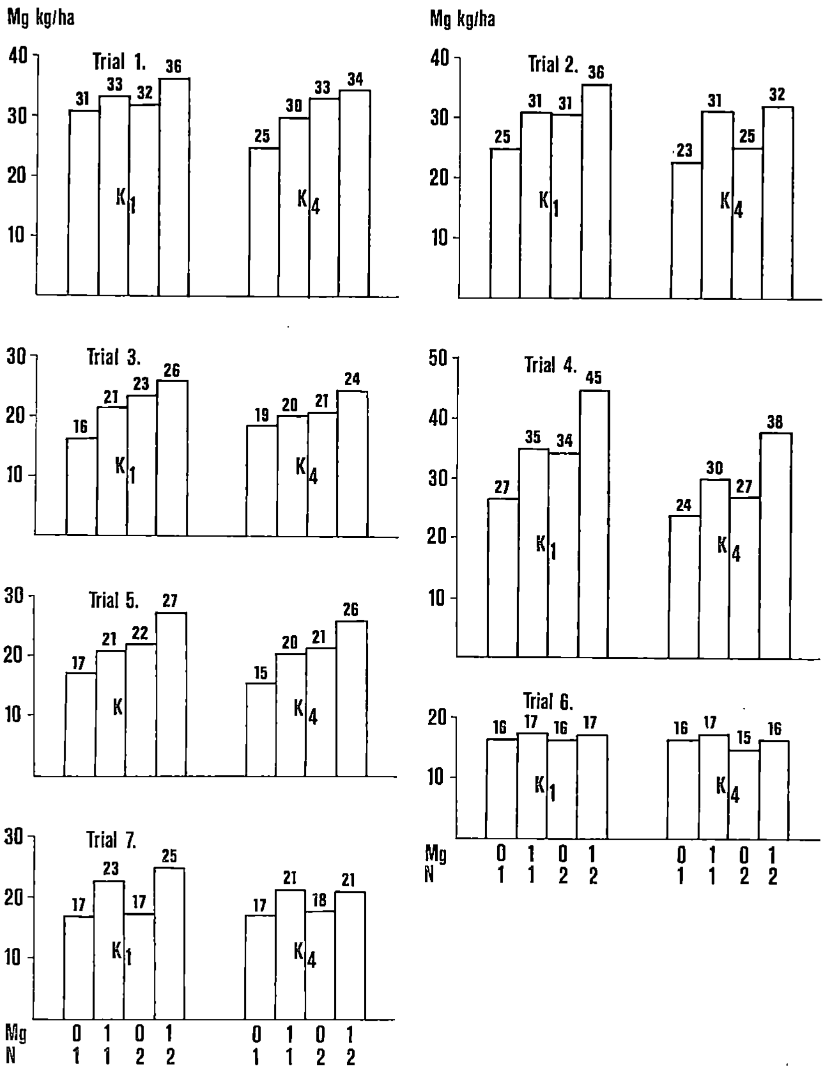

Fig. 1. The amount of magnesium (Mg ka/ha) taken up by crops in five years (the number at the top of the column) at various test sites. (Mg_1 = 57 kg/ha Mg, N_1 = 50 and N_2 = 100 kg/ha N, K_1 = 60 and K_4 = 240 kg/ha K)

The increase in the amount of potassium fertilizer from 60 to 240 kg reduced the uptake of magnesium by grassland crops by an average 0,9 kg/ha/a (7,6—6,7 kg/ha/a, 12 %).

The highest uptake of magnesium by crops wich received no magnesium fertilizer at any time during the experimental period was in experiment 1, in which the magnesium lost along with the crops was 30 kg/ha (Fig. 1). The soil magnesium reserves were depleted least by the plants in experiments 6 (16 kg/ha) and 7 (17 kg/ha).

Magnesium fertilizer increased the uptake of magnesium by the crops at all seven sites. The greatest increase in magnesium uptake was in experiment 4, in which it amounted to 8,9 kg/ha (32 %). In experiment 6 the increase in magnesium uptake amounted to only 1 kg/ha (6 %). The main reason for this small increase in the uptake of magnesium is the fact that a cereal crop was grown in this experiment throughout the entire experimental period.

Increasing the amount of nitrogen fertilizer from 50 to 100 kg produced a significant increase in the uptake of magnesium in experiments 1—5. The largest increase in the uptake of magnesium was seen in experiment 4 (7 kg/ha, 24 %) and the smallest in experiments 1 and 3 (4,5 kg/ha).

The amounts of potassium fertilizer used in this study did not significantly affect the uptake of magnesium in any of the experiments. The higher amount of potassium fertilizer reduced the uptake of magnesium most in experiment 4 (5,4 kg/ha, 15 %) and least in experiment 6 (0,6 kg/ha, 4 %).

The greatest amount of magnesium (30 kg/ha), calculated as the average of all the experiments, was lost from the soil during the five-year experimental period when the plants were given magnesium fertilizer in addition to the small amount of potassium and the larger amount of nitrogen (Fig. 2). The lowest uptake of magnesium (20 kg/ha) by the crops occurred when, in addition to a large amount of potassium fertilizer, a small amount of nitrogen and no magnesium

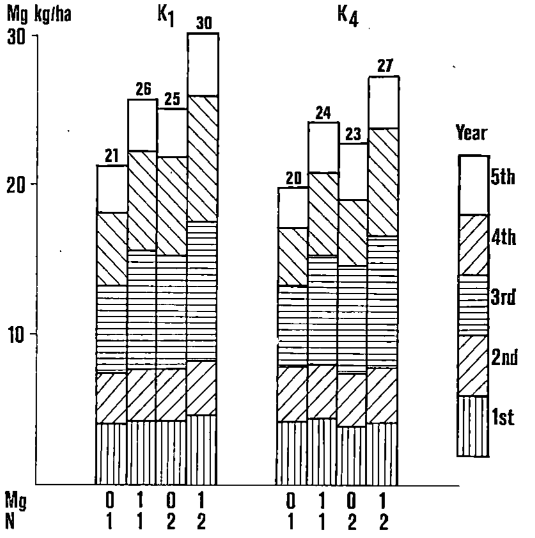

Fig. 2. The amount of magnesium (Mg kg/ha) taken up by crops and the total in five years (the number at the top of the column). Explanations of the symbols in figure 1. (1st and 2nd year: 7 spring cereals, 3rd and 4th year: 6 grass and 1 spring cereal, 5th year: 6 spring cereals and 1 grass)

were applied. The average uptake of magnesium without magnesium fertilizer was 22 kg/ha and with the application of magnesium sulphate 27 kg/ha in five years. The results representing the uptake of magnesium by second and third year crops are the averages of six grassland crops and one cereal crop. In the fifth year cereals grew in six experiments and grass in one experiment, and the results are the averages of these.

Of the magnesium applied annually as fertilizer (57 kg/ha) cereal crops took up an average of 0,3 kg/ha (0,5 %) and grasslands an average of 2,1 kg/ha (3,7 %). The total apparent recovery of annually applied fertilizer magnesium used in this study varied between 1,0 and 8,9 kg/ha (0,4—3 %) on the various sites and had a mean value of 4,6 kg/ha (1,6 %, Table 3). The greatest amount of magnesium applied as fertilizer was taken up in experiment 4. The amounts of potassium and nitrogen fertilizer had different effects on the utilization of magnesium

Table 3. The effect of the amounts of potassium and nitrogen fertilizer during five years on the apparent recovery (kg/ha, %) of the magnesium applied as fertilizer (285 kg/ha Mg) at different test sites. (Differences Mg_1—Mg_0.)

Trial no.	K_1		K_4		Recovery	
	N_1	N_2	N_1	N_2	kg/ha	%
1	2,4	4,4	4,9	1,5	3,5	1,2
2	6,1	5,1	8,6	7,0	6,7	2,4
3	5,1	2,6	1,6	3,7	3,3	1,1
4	8,3	10,3	6,2	10,8	8,9	3,1
5	3,8	4,9	5,0	4,7	3,4	1,2
6	0,9	0,7	0,7	1,6	1,0	0,4
7	5,8	7,4	4,3	3,2	5,2	1,8
Mean						
kg/ha	4,6	5,1	4,5	4,6		
%	1,6	1,8	1,6	1,6		

Table 4. The volume of fertilizer magnesium (mg/l, %) discovered in the yields and soil at different test sites. (Differences Mg_1—Mg_0.)

Trial no.	Magnesium uptake of the yield mg/l	Soil (0—20 cm) magnesium content mg/l	Total		Soil (20—40 cm) magnesium content mg/l
			mg/l	% of the applied	
1	1,5	28	29,5	21	10
2	3,5	47	50,5	35	3
3	1,5	57	58,5	41	8
4	4,5	40	44,5	31	29
5	2,5	17	19,5	14	24
6	0,5	64	64,5	45	3
7	2,5	54	56,5	40	3

applied as fertilizer, although the average differences were not great.

The crops utilized the magnesium applied as fertilizer only to a small extent in spite of the fact that the experiments in this study were carried out on soil whose plough layer contains less than 100 mg/l of magnesium (acid ammonium acetate-extractable). The plough layer was assumend to contain 2 million litres of soil per hectare. During the five years the crops took 0,5—4,5 mg of magnesium from one litre of soil (Table 4). The acid ammonium acetate-extractable magnesium content of the soil in the plough layer of various sites was 17—64 mg/l higher at the end of the experimental period than at the beginning on plots treated with magnesium fertilizer. It was possible to analyse a maximum of 45 % of the magnesium given as fertilizer (143 mg/l) in the crops and in the plough layer of soil. More than half of the fertilizer magnesium remained in the soil in a form insoluble in acid ammonium acetate or had been leached out of the plough layer into the subsoil. At the end of the experimental period the magnesium content of the soil beneath the plough layer (20—40 cm) had increased by 29 mg/l in experiment 4 and by 24 mg/l in experiment 5, compared with soil not treated with fertilizer. The corresponding increase in magnesium content in experiments 2, 6 and 7 was 3 mg/l. If the increase in magnesium content were due solely to the magnesium applied as fertilizer, it would correspond to 2—20 % of the magnesium given.

However, in view of the fact that when starting the experiments only the magnesium content of the plough layer was determined, changes in the magnesium content of the soil beneath this layer cannot be elucidated during the experimental period.

Calcium uptake

The amount of calcium taken up anually by cereal grain varied from 1,6 to 2,6 kg/ha (Fig.3). Grassland hay and aftergrowth crops took up calcium as follows:

	Ca kg/ha/a
Hay	15,6
Aftergrowth	6,6
Total	22,2

The smallest amount of calcium taken up by the hay and aftergrowth crops together, 11 kg/ha/a, came from soil treated with fertilizer corresponding to $N_1K_1Mg_1$, and the greatest amount, 27 kg/ha/year, from soil treated with with N_2K_1 and without magnesium.

More calcium was removed from the soil by grassland crops with the larger amount of nitrogen fertilizer than with the smaller. The larger

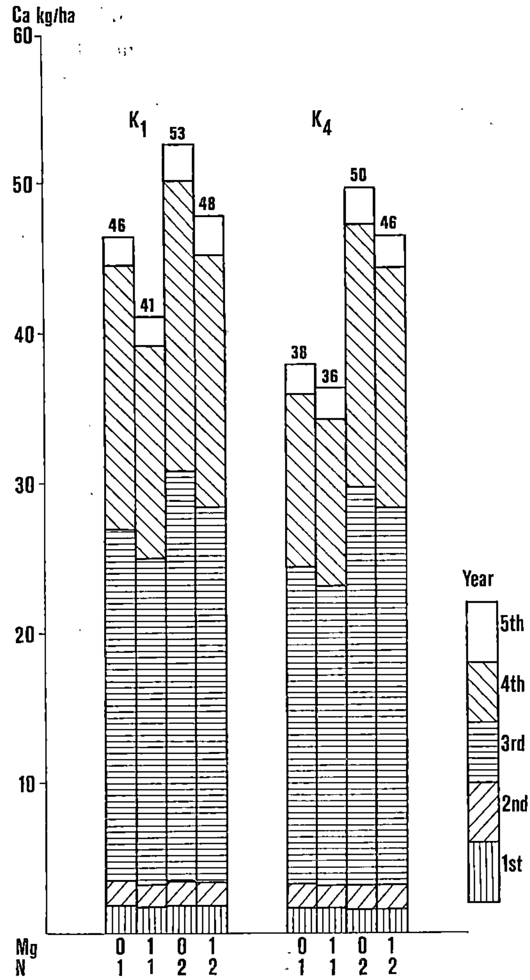

Fig. 3. The amount of calcium (Ca kg/ha) taken up by crops in different years and the total in five years (the number at the top of the column). Explanations of the symbols in figure 1. (1st and 2nd year: 7 spring cereals, 3rd and 4th year: 6 grass and 1 spring cereal, 5th year: 6 spring cereal and 1 grass)

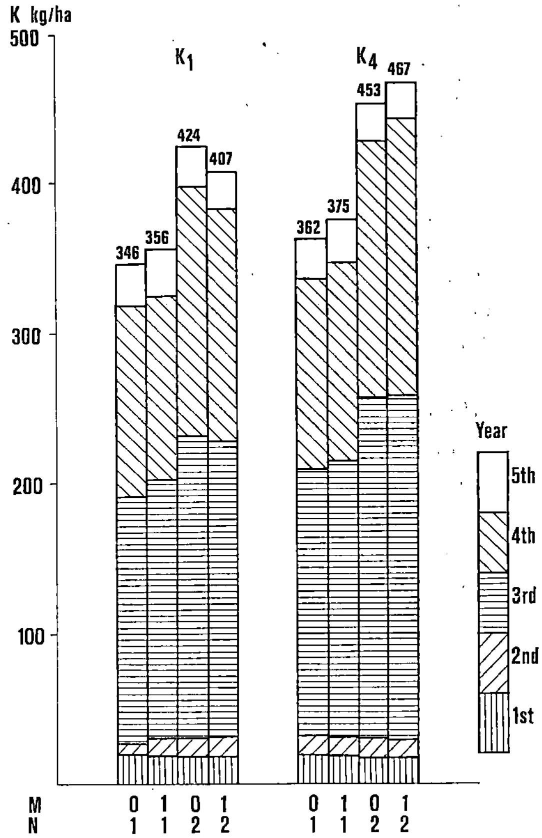

Fig. 4. The amount of potassium (K kg/ha) taken up by crops in different years and the total in five years (the number at the top of the column). Explanations of the symbols in figure 1. (1st and 2nd year: 7 spring cereals, 3rd and 4th year: 6 grass and 1 spring cereal, 5th year: 6 spring cereals and 1 grass)

amount of potassium and the application of magnesium fertilizer both reduced the uptake of calcium by the grassland crops.

During the five-year experimental period the crops took up 36—53 kg/ha of calcium. The highest uptake of calcium by the three cereal crops and two grass croxs was in experiment 1 (claeye finer fine sand) and the least in experiment 5 (finer fine sand). At the start of the study the plough layer in experiment 5 contained only 370 mg/l of calcium. One reason for the high uptake of calcium in experiment 1 may be the fact that the stand contained clover.

Potassium uptake

The total uptake of potassium in three cereal and two grass crops in five years varied from 346 to 467 kg/ha, depending on the experimental treatment (Fig.4). The greatest effect on potassium uptake was where nitrogen fertilizer had been applied. With the smaller amount of nitrogen 358 kg/ha of potassium was removed with the crops in five years and 437 kg/ha with the larger amount of nitrogen fertilizer.

In the first two years the potassium uptake of the grain varied from 8,6 to 19,0 kg/ha annually. During the next years the uptake of potassium with experimental treatments was from 122 (N_1K_1Mg) to 229 kg/ha (N_2K_4Mg) annually. The largest total amount of potassium taken up by three cereal and two grass crops was removed from experiment 4 (maddy finer fine sand), from which the largest crops in this study were obtained. Crops on finer fine sand in experiment 5 took the least potassium in this field test series. At the beginning of the experiments, there was nearly the same amount of potassium in the soil of both experiment sites.

The smaller amount of potassium fertilizer, a total of 150 mg/l of soil as K (300 kg/ha) in five years, was not entirely sufficient for the needs of three cereal and two grass crops, because the amount of acid ammonium acetate-extractable potassium in the plough layer declined by 33 mg/l on average. The crops had also taken up an additional 9 mg/l of potassium, either in readily soluble form beneath the plough layer or in not very soluble form from the entire root system layer, since the uptake of potassium by the crops totalled 192 mg/l of soil. The smaller amount of potassium was sufficinet for the finer fine sand in experiments 1 and 5. In other experiments the potassium content of the soil decreased.

The larger amount of potassium, 600 mg/l of soil as K (1200 kg/ha), raised the amount of readily soluble potassium in the plough layer by 177 mg/l and the crops took up 207 mg/l (34,5 %). Of the potassium applied, 216 mg/l of soil may have been retained extractable in acid ammonium acetate or have been shifted below the plough layer. The potassium content of the soil beneath the plough layer (20—40 cm) on the plots which received the larger amount of potassium was on average 71 mg/l higher than on the plots with the smaller amount of potassium.

DISCUSSION

The cereal grain yields took up an average of 3,4 kg/ha of magnesium without magnesium fertilizer, and the magnesium of the soil in this study which had even a meagre magnesium content was sufficient for producing a crop. The amount of magnesium returning to the soil along with the straw may be nearly as much as that taken up by the grain crop (Jokinen 1977 a). It can be said that the magnesium content of the soil rarely limits the growth of cereals in Finland, for the magnesium in the soils in the cereal-growing area of the southern part of Finland may be sufficient, except in the coarse mineral soils (Kaila 1973). Some of the multi-nutrient fertilizers on sale in Finland contain so much magnesium (1,0—2,5 %) that the amount of magnesium taken up by the cereal crops is replaced with the fertlizer.

The amounts of nutrients removed in the grass crops depended both on the amount of the crop and on the changes in its nutrient contents. In contrast, the amount of the grain crop with cereals was decisive (Jokinen 1977 b).

An increase in nitrogen fertilizer enhanced the uptake of magnesium, potassium, calcium and nitrogen by grass species (Håland 1971, Sillanpää and Rinne 1975). The quadruple amount of potassium fertilizer did not have a significant effect on the uptake of magnesium (Laughlin et al. 1973).

Without magnesium fertilizer the crops took up 22 kg/ha of magnesium in five years. During the same period the magnesium content of the soil (acid ammonium acetate-extractable) declined by 17 mg/l (c. 33 kg/ha). The apparent recovery of the annual application of magnesium in these field experiments was low (1,6 % on average), although the soils did contain a small amount of magnesium. The rise in the magnesium content of the soil caused by the fertilizer was significant at all test sites. On this basis it can be assumed that the recovery of magnesium would be greater than the above-mentioned. In some studies it has been found that the magnesium content of crops remains high for several years after fertilizer has been applied (JOKINEN 1971, HARRIS 1977). The apparent recovery of the magnesium applied as fertilizer may therefore be larger than this study indicates. During the three-year period one cereal crop and two grass crops took up some 3 % (a total of 285 kg/ha Mg) of the magnesium applied during the first two years (JOKINEN 1977 b). The apparent recovery of the magnesium (95 kg/ha) applied at one time on the studies of JAAKKOLA and VOGT (1978) was some 1,7 % in three years. In pot experiments lasting three years the grain and straw yields of oats on bog peat used a total of 13—64 % of the magnesium in the magnesium sulphate applied annually (JOKINEN 1977 a). A large amount of nitrogen fertilizer and liming increased the capacity of the cereal to use the magnesium applied in the form of fertilizer.

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SELOSTUS

Magnesium-, kalium- ja typpilannoituksen vaikutus kevätviljojen ja nurmien ravinteiden ottoon

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Maatalouden tutkimuskeskus

Magnesiumsulfaattilannoituksen (57 kg/ha Mg) vaikutusta kevätviljojen ja nurmien ravinteiden ottoon tutkittiin kenttäkokeissa kahdella kaliumkloridi- (60 tai 240 kg/ha K) ja kahdella kalkkisalpietarilannoituksen (50 tai 100 kg/ha N) tasolla. Lannoitukset annettiin viiden vuoden koejakson aikana vuosittain kasvukauden alussa. Kokeissa kasvoi kahtena ensimmäisenä vuotena vilja, kolmantena ja neljäntenä vuotena nurmi, viidentenä vuotena vilja. Seitsemästä kokeesta kuusi oli perustettu alle 100 mg/l Mg sisältävälle maalle.

Ilman magnesiumlannoitusta poistui maasta jyväsadon mukana magnesiumia keskimäärin 3,4 kg/ha vuodessa. Lannoituksena annettua magnesiumia jyväsadot ottivat vuosittain 0,3 kg/ha (0,5 %).

Nurmista korjatut heinä- ja odelmasato yhdessä ottivat vuosittain keskimäärin 6,1 kg/ha magnesiumia, jos magnesiumlannoitusta ei annettu. Magnesiumin otto lisääntyi 2,1 kg/ha, kun lannoituksena annettiin vuosittain 57 kg/ha magnesiumia. Nurmen sadot ottivat lannoitteen magnesiumia 3,7 %.

Viiden vuoden koejakson aikana annetun magnesiumin näennäinen hyväksikäyttö vaihteli koepaikan mukaan 1,0—8,9 kg/ha (0,4—3 %). Keskimääräinen hyväksikäyttö tämän tutkimuksen viljelykierrossa oli 4,6 kg/ha (1,6 %). Magnesiumlannoituksen jälkivaikutusta ei tutkittu.

ANNALES AGRICULTURAE FENNIAE, VOL. 18: 213—217 (1979)

Seria ANIMALIA DOMESTICA N. 50 — Sarja KOTIELÄIMET n:o 50

RESEARCH NOTE
THE USE OF BEEF BULLS ON DAIRY COWS

ULF B. LINDSTRÖM

LINDSTRÖM, U. B. 1979. **The use of beef bulls on dairy cows.** Ann. Agric. Fenn. 18: 213—217. (Agric. Res. Centre, Inst. Anim. Breed., SF-01300 Vantaa 30, Finland.)

Interviews and records from 415 herds inseminating part of their dairy cows with beef semen indicated that over 90 % of the owners considered the effect of the sire of the fetus on the dam's milk production and fertility negligible. Reductions in milk yield were, however, observed somewhat more frequently at high average production levels. There were no differences between Charolais-mated and Hereford/Aberdeen Angus-mated cows as regards milk production or fertility.

INTRODUCTION

In the past few years evidence has been accumulating on an influence of the sire of the fetus on the milk production of the dam (SKJERVOLD & FIMLAND 1975, ADKINSON et al. 1977, TAYLOR et al. 1978). Recently NIELSEN & JØRGENSEN (1979) reported a decrease of 12—14 kg of butterfat per lactation, i.e. 4—5 %, of Jersey cows pregnant in their first lactation with a Charolais-sired fetus.

Two years ago we did a survey of the experiences of dairy herd owners using beef semen regularly to part of their cows. This type of study does not provide exact figures on the effects beef sires have on the dams they are mated to. Nevertheless it gives useful results of the magnitude of the possible beef sire influence. As this report is available only in Finnish (LINDSTRÖM 1978), and as we know of only one other field study on this subject (STEGENGA et al. 1972), it seems worthwile to present some of our results in the form of a note.

MATERIAL AND METHODS

In recent years some 50—60 000 dairy cows have annually been inseminated with semen from beef bulls. Of these approximately one half have been milk recorded cows. From the registers of the Agricultural Computing Centre (ACC) the names and addresses of all owners using beef bulls in their milk recorded herds in 1975 and 1976 were collected. At the end of 1977 every third of these, i.e. 748 owners, were sent a questionnaire asking for information on beef breeds used, age and milk yield of cows inseminated, calving difficulties, still births etc. The question concerning the effects of the beef bulls on the cows was formulated as follows: »Which were the effects of the beef bull(s) on the inseminated cow(s)?»

	Improved	No effect	Decreased
(a) On the pregnancy rate and fertility			
(b) On the milk production in the current lactation			
(c) On the milk production in the following lactation			

The questionnaire was returned by 415 herd owners (56 %). The answers were coded, punched and supplemented with information on breed composition, herd size, average milk yield of herd and area from the registers of ACC. Frequency distributions for the whole material and for various subgroups were calculated. Differences between proportions were tested by t-tests. Herds with more than 60 % of the cows of one breed were considered purebred. The majority (60 %) of the herds were Ayrshire, 3 % were Finncattle, 5 % Friesian and the rest mixed. Most herds, over 3/4, were from South or Central Finland. Approximately 30 % of the herds had less than 8 cows.

RESULTS

General

Over half of the herd owners had been using beef bulls for 5 years or longer. Of the beef breeds Charolais was used most, to 61 %, the Hereford to 32 % and Aberdeen Angus to 7 %. Only 16 % of the herds had used beef bulls to heifers. The majority of the farmers used beef semen to cows at least 3 years old, mainly to poor or average individuals. Charolais was used to 65 % of the cows in small (< 8 cow) herds, but only to 50 % in larger herds. Hereford semen was used to less than 30 % in small herds, but to c. 40 % in larger herds. Large herd owners (specialised in milk production) seemed more anxious to avoid the negative effects, e.g. increased risk for calving difficulties, of using a large Charolais bull than owners of small herds. An interesting observation was that the usage of Charolais increased from 59 % in herds yielding less than 5 000 kg/cow to 69 % in herds producing more than 6 500 kg/cow. The reason is probably that in high producing herds the poorest cows are more easily identified and set aside for beef bull crossings than in low producing herds.

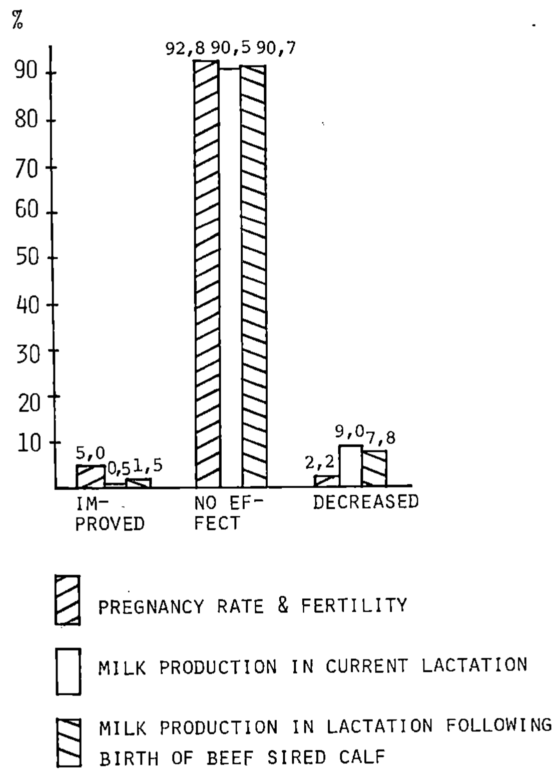

Fig. 1. Effect of beef bull on the inseminated dairy cow.

Effect of sire

Fig. 1. gives the results for the whole material of the effect of the beef bull on the inseminated cow. Obviously the majority of the herd owners consider the influence of the beef sire small. This is especially true with respect to the pregnancy rate & fertility of the cow; only 2,2 % reporting a decrease while 5 % note an improvement. For milk production the proportion reporting a decrease is clearly higher, 9 and 8 % for the current and subsequent lactation, respectively. Only 0,5 and 1,5 % report an improvement. The great majority, over 90 %, do, however, consider the effect of the beef sire negligible. These results are in agreement with those of STEGENGA et al. (1972), who found no difference between the milk yield of Charolais and Friesian mated dams. In our study, among the farmers noting a reduced milk yield many also commented on a prolonged dry period. This is in agreement with NIELSEN & JØRGENSEN (1979).

Production level, herd size

An interesting feature is that the proportion of farmers observing a decrease in milk yield increased with increasing average herd levels. (Table 1.). This increase is, however, not statistically significant neither in the current nor subsequent lactation. There was no clear difference between the results for Charolais- mated dams compared to Hereford/Aberdeen Angus-mated dams. Although the proportion of farmers reporting a decrease in milk yield increased with increasing herd size (Table 2.), this tendency was not significant neither for the current nor for the subsequent lactation. The differences between the Charolais- mated and Hereford/Aberdeen Angus- mated dams were also here negligible.

Table 1. Influence of beef sire on milk production of inseminated cow at two herd production levels.

Production level kg, milk	Percent of owners reporting decrease in milk yield			
	Current lactation		Subsequent lactation	
	N	%	N	%
<5 500 ..	183	6,1	179	6,5
6 000— ..	136	10,6	131	8,4

Table 2. Influence of beef sire on milk production of inseminated cow at varying herd sizes.

Herd size Nos. of cows	Percent of owners reporting decrease in milk yield			
	Current lactation		Subsequent lactation	
	N	%	N	%
<8	127	8,1	125	4,9
9—15	204	7,7	200	6,6
16—	84	13,4	80	15,3

If the beef-sired fetus exerts an influence on the dam one would, naturally, expect a larger reduction at high than at low milk production levels. The above results are consistent with this theory. The influence of the herd size seems more difficult to explain. However, in our material the herds with 16 or more cows had an average production some 200 kg higher than those with less than 8 cows. There is thus confounding between herd size and production level. Moreover, because of more flexible selection opportunities, it is possible that the cows inseminated with beef bulls, on average, are somewhat better in large than in small herds. (Unfortunately we did not have data on this).

With regard to **pregnancy rate/fertility** there were no differences between dams mated to Charolais and Hereford/Aberdeen Angus nor between dams producing at different production levels and in herds of varying size.

Neither were any significant differences between **cows of different ages** detected with regard to milk production nor fertility. As only 16 % of the farmers had used beef bulls to heifers and only 3 % had done so regularly, it was not possible to analyse the beef sire influence on young animals.

Reasons for »fetus-effect»

At present the reasons for a »fetus-effect» are unclear. Although hormone secretions (oestrogen, progesteron, lactogen) of the placenta certainly are involved (Osinga 1970, Bolander et al. 1976, Mollett et al. 1976) the exact mechanisms and the influences of other factors are unknown. Conflicting results have been presented on the effect of the genetic quality (for milk yield) of the sire of the fetus. Skjervold & Fimland (1975) and Adkinson et al. (1977) found no association between the milk breeding value and the »fetus-effect» of a sire whereas Taylor et al. (1978) noted a significant negative one. It seems that the weight of the fetus also plays an important part, larger fetuses generally producing more oestrogen. This effect may, however, be different for beef and dual purpose bulls (Osinga 1970). But perhaps the weight of the fetus as such also influences the milk yield of the dam? There may thus be confounding between the growth rate of a sire, its association with his daughters' milk production and the »fetus effect».

CONCLUSION

If the milk depressing effect of the beef-sired fetus were very pronounced, say 10—15 %, it seems probable that even in this material a far larger proportion of the farmers would have reported on it. The fact that reductions in milk yield were observed more frequently at higher average production levels indicates, however, that the beef sire influence, although small, perhaps isn't completely negligible.

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SELOSTUS

Pihvisonnien käyttö lypsykarjoissa

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Maatalouden tutkimuskeskus

Yhteensä 415 lypsykarjasta saatujen haastattelu- ja karjantarkkailutulosten perusteella todettiin, että yli 90 % karjanomistajista ei pitänyt pihvisonnin vaikutusta siemennetyn lehmän hedelmällisyyteen tai maidontuotantoon mainittavana. Korkealla (> 6 000 kg) tuotostasolla olevissa karjoissa todettiin kuitenkin hieman useammin maidontuotannon vähennystä. Charolais-sonneilla siemennettyjen lehmien ja Hereford/Aberdeen Angus-sonneilla siemennettyjen lehmien välillä ei ollut eroa maidontuotannossa eikä hedelmällisyydessä.

ANNALES AGRICULTURAE FENNIAE, VOL. 18: 218—224 (1979)
Seria AGROGEOLOGIA ET -CHIMICA N. 94 — Sarja MAA JA LANNOITUS n:o 94

SEASONAL VARIATIONS IN MICRONUTRIENT CONTENTS OF WHEAT

Toivo Yläranta, Håkan Jansson and Jouko Sippola

Yläranta, T., Jansson, H. & Sippola, J. 1979. **Seasonal variations in micronutrient contents of wheat.** Ann. Agric. Fenn. 18: 218—224. (Agric. Res. Centre, Inst. Soil Sci., SF-01300 Vantaa 30, Finland.)

The B, Cu, Fe, Mn, Mo, and Zn contents of spring and winter wheats were analyzed twice a week during the growing season in order to obtain data on seasonal variation in micronutrient contents of plants.

The highest contents of B, Cu, and Fe, recorded at an early stage of growth, were followed by substantial decreases towards the end of the growing season. The decreases in boron were from 4—12 to less than 2 mg/kg, in copper from 6—10 to 3—4 mg/kg and in iron from 80—210 to 30—75 mg/kg.

The highest Mo and Mn contents were also found at early stages of growth. At later stages the changes in the contents were less regular and in the case of Mn a tendency to increase was observed toward harvesting time.

The behaviour of Zn differed from that of other micronutrients studied. The changes in Zn contents were relatively small, consisting mainly of a slight tendency to increase towards the later stages of growth.

The differences in soil micronutrient contents were best reflected in the respective wheat micronutrient contents at the early stages of plant growth. Therefore, samples for plant analysis should be taken at an early stage of plant growth. There were no clear differences in the contents nor in the behaviour of micronutrients between the spring and winter wheats.

Index words: Wheat, stage of growth, contents of boron, copper, iron, manganese, molybdenum and zinc.

INTRODUCTION

The highest levels of macronutrient contents (Ca, K, Mg and P) in wheat occur at a very early stage of plant development, and the concentrations decrease rapidly as the plant grows older (e.g. Sippola et al. 1978).

Both plant and soil analysis have been used to study the need for fertilization in crop growing. One disadvantage of plant analyses is that they can only be made during the growing season when the time available for deficiency corrections is limited and the result may be ineffective. Therefore, presowing fertilization with macronutrients according to soil tests is a widely accepted practice. In the case of micronutrients the amounts needed are small and they may be applied to the crop together with herbicide or fungicide treatments. For this reason plant analysis may offer more advantages in the case of micronutrients than with macronutrients.

For proper interpretation of analytical results a knowledge is required of possible changes in the micronutrient content during growth. The contents of boron, copper, iron, manganese, molybdenum and zinc during the growing period in winter and spring wheats are recorded in this study.

MATERIAL AND METHODS

Spring and winter wheats were grown on four experimental fields located at Tikkurila in southern Finland and at Mouhijärvi in central Finland. At Tikkurila the spring wheat (variety Ruso) was grown on a sandy clay soil and winter wheat (Nisu) on a sand soil. At Mouhijärvi the respective soils and varieties were clayey silt (Svenno) and silty clay (Linna). The sowing dates were 2. 9. 1975 and 21. 5. 1976 at Tikkurila, and 18. 8. 1975 and 22. 5. 1976 at Mouhijärvi. The average fertilization consisted of 100 kg N, 35 kg P and 47 kg K, 25 kg Ca and 3 kg Mg per hectare.

The micronutrients (Fe, Cu, Mn, Mo and Zn) were extracted from the soil using a 0,02 M Na_2EDTA, 0,5 M ammonium acetate, 0,5 M acetic acid solution, pH 4,65 (Lakanen and Erviö 1971). Boron was extracted using a modified Berger and Truog (1945) method. Soil (25 ml) and H_2O (50 ml) were boiled together for 5 min in a silica flask using a test tube with water circulation as a condenser in the neck of the flask. The solution was immediately filtered through a fluted filter paper. Boron was determined by an azomethine-H method (Sippola and Erviö 1977). Analytical data of soils are given in Table 1.

Table 1. Properties of experimental soils as analyzed at sowing and at harvesting time.

	pH(H_2O) 1 : 2,5	mg/l soil					
		B	Cu	Fe	Mn	Mo	Zn
Winter wheat							
Tikkurila, sandy clay							
sowing	5,1	0,75	5,30	568	65	0,057	11,4
harvest	5,1	0,66	5,19	569	72	0,057	11,3
Mouhijärvi, silty clay							
sowing	5,5	0,39	2,24	266	111	0,082	2,9
harvest	5,9	0,42	2,41	303	130	0,084	3,2
Spring wheat							
Tikkurila, sand							
sowing	5,8	0,57	2,43	278	16	0,023	8,4
harvest	5,9	0,53	2,56	292	18	0,027	10,5
Mouhijärvi, clayey silt							
sowing	5,3	0,31	1,46	298	115	0,039	3,1
harvest	5,5	0,30	1,52	310	114	0,037	3,5

The wheat samples were collected twice a week during the growing season. Each sample consisted of ten sub-samples (the upper halfes of the plants was collected) from an area of about 0,2 hectare.

Plant samples were analyzed by a previously described method (Sippola et al. 1978). The molybdenum was determined by the zinc dithiol method (Stanton and Hardwick 1967). The azomethine-H method (Sippola and Erviö 1977) was used in the boron determinations.

RESULTS AND DISCUSSION

The results of plant analyses are given in Fig. 1 and 2 as moving averages of order three.

Boron

The boron contents of the wheats at Tikkurila varied from about 10 mg/kg DM (dry matter) in early summer to about 2 mg/kg at harvesting time, and at Mouhijärvi from 4—6 mg/kg to about 1—2 mg/kg, respectively (Fig. 1). The considerably higher contents of extractable B from Tikkurila soils are clearly reflected in the boron contents of the wheats in June. In July these differences decrease and at the later stages of growth in the case of winter wheat the differences disappear.

Copper

The copper contents of spring and winter wheats at Tikkurila were 8—10 mg/kg in early summer and decreased to 2,5—3,5 mg/kg towards harvesting time. The contents at Mouhijärvi decreased from about 6 to 3—4 mg/kg. No clear differences existed between the spring and winter wheats. Since different varieties were grown at Tikkurila and at Mouhijärvi the varietal effects and effects of extractable Cu contents of soils on the Cu contents of the plants cannot be clearly defined. However, in early summer the Cu contents of wheats grown at Tikkurila were almost twice as high as those of the Mouhijärvi wheats. This may be due to a similar relation between the extractable Cu contents in respective soils (Table 1). The differences in the Cu contents of wheats disappeared at later stages of growth and in the case of the spring wheat reversed.

Iron

The highest iron contents of wheats (80—210 mg/kg) were recorded at the very early stages of growth at all four experimental sites. The high Fe content of Tikkurila winter wheat is obviously due to the high extractable content of Fe in that particular soil (Table 1). The decrease in Fe contents of wheats towards the later stages of growth (to 30—50 mg/kg) is distinct even though some tendency to increase can be noticed when approaching the harvesting time.

Manganese and Molybdenum

The changes in Mn and Mo contents of wheats during the growing period were not as clearly defined as in the case of Cu, Fe and B.

The Mo contents of wheats varied from about 0,1 to 0,7 mg/kg being at a maximum at early stages of growth. At later stages, the changes in the Mo contents were less regular, staying within the limits of 0,1—0,4 mg/kg. A partial reason for the high Mo contents of Tikkurila spring wheat and Mouhijärvi winter wheat may be the high pH of the respective soils.

The range of variation in Mn contents for the four wheats under study was about 30—100 mg/kg. The Mn contents were at a maximum about four weeks after sowing the spring wheats (middle of June) and at the respective stage of growth in the case of winter wheats (early June). After this the contents decreased markedly, reaching a minimum at about the middle of July. The minimum was followed by an increase towards the end of the growing season.

The exceptional changes in Mn contents of wheats may be connected with the redox conditions of soils during the growing season. The high Mn contents of Tikkurila winter wheat and Mouhijärvi spring wheat may be at least partially due to higher availability of Mn in soils of lower pH.

Zinc

The variation in the zinc contents of wheats were surprisingly small compared with other micronutrients. The Zn contents at Tikkurila varied between 25 and 40 mg/kg and at Mouhijärvi between 20 and 25 mg/kg. The zinc contents of the wheats increased slightly during the whole growing period. The extractable content of Zn was considerably higher in Tikkurila soils than in Mouhijärvi soils. This difference is clearly reflected in the Zn contents of plants at all growing stages.

Micronutrient content of Finnish wheat

Data on micronutrient contents of wheats grown in Finland and elsewhere vary greatly. Among the factors causing this variation are the differ-

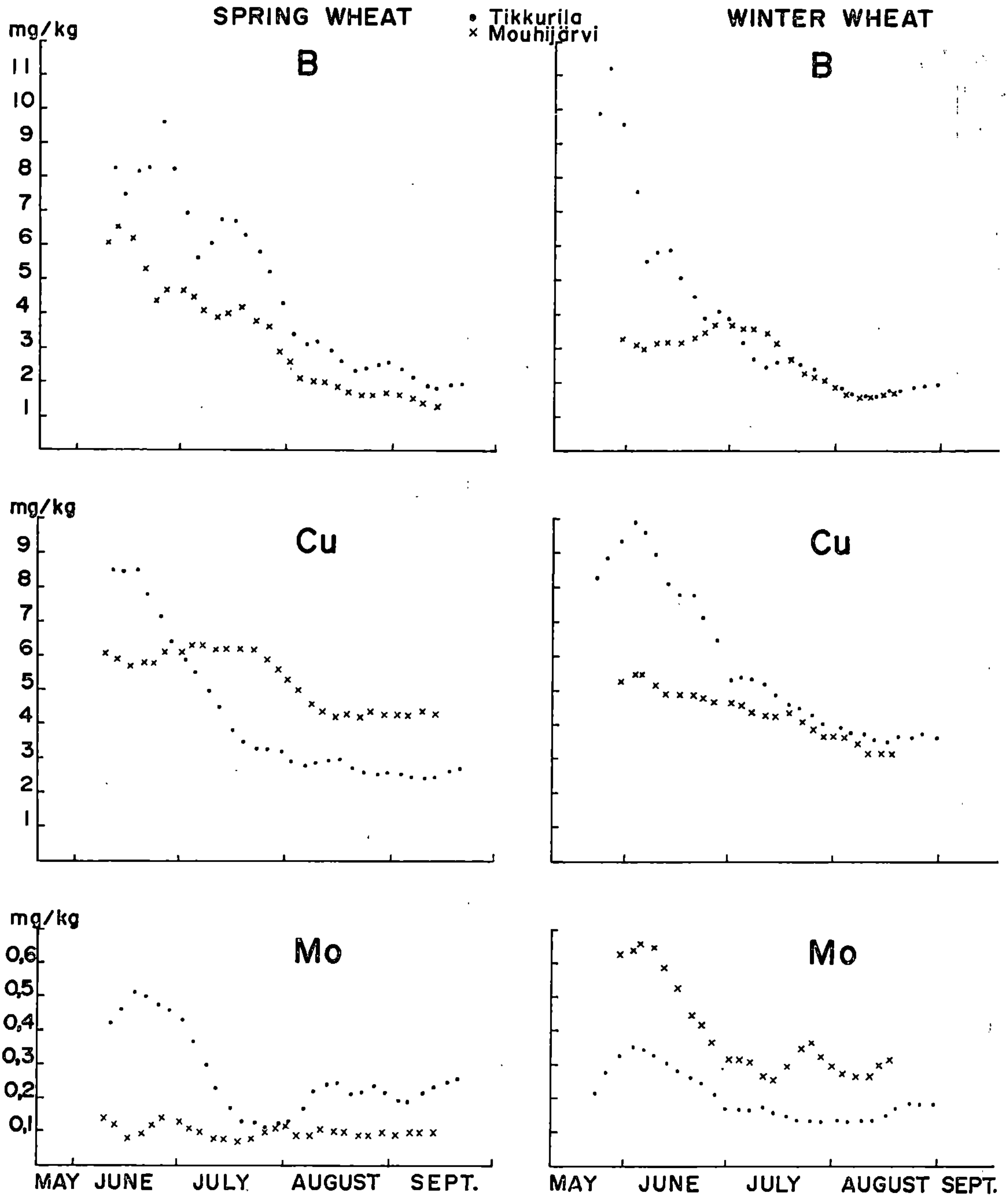

Fig. 1. Boron, copper and molybdenum contents of spring and winter wheats during the growing season at two locations.

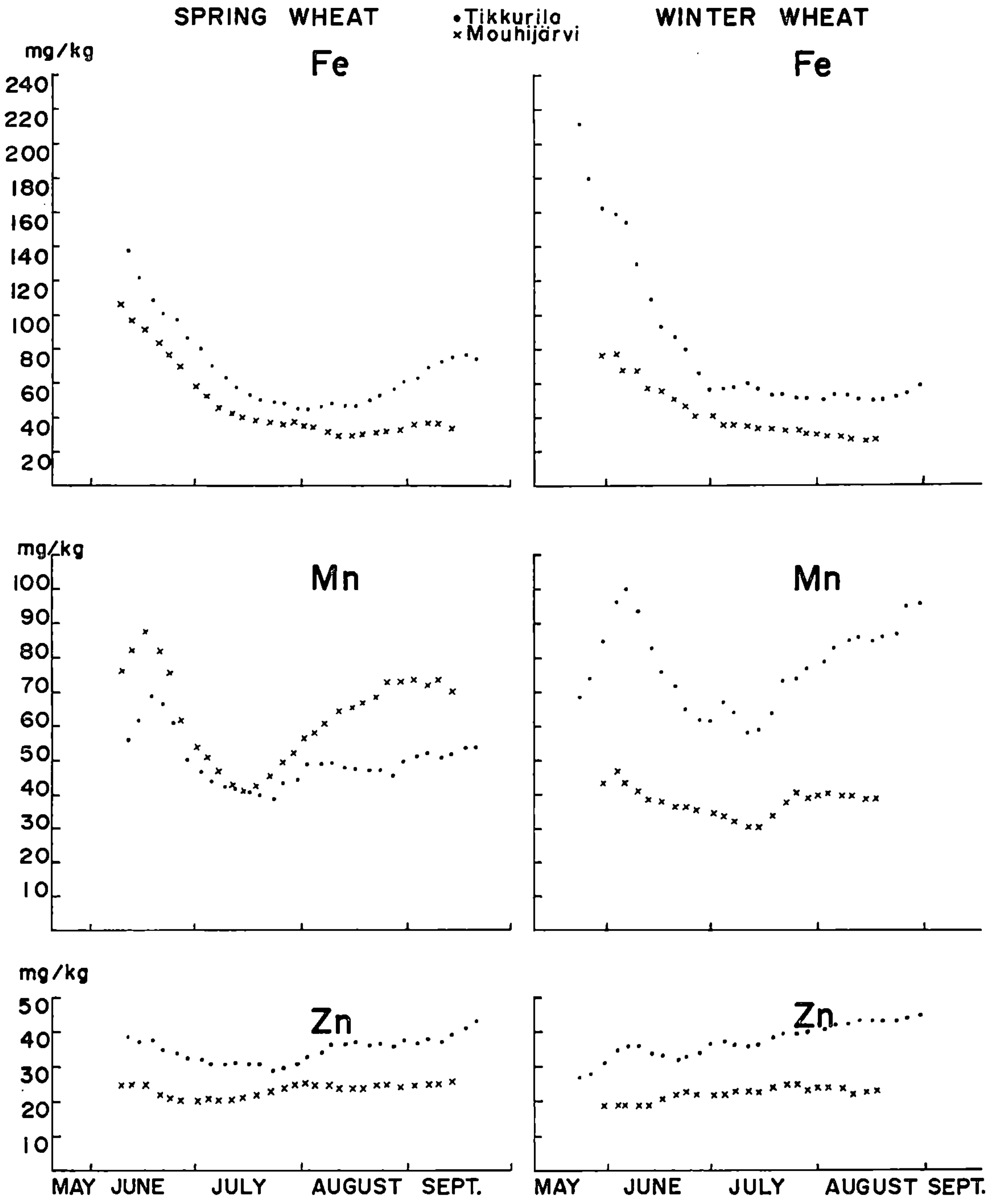

Fig. 2. Iron, manganese and zinc contents of spring and winter wheats during the growing season at two locations.

ences in soils, in the growing stage of the wheat at the sampling time, in plant parts selected for analysis and in analytical methods.

Micronutrient contents of wheats similar to those in Finland have been reported, e.g. from Austria and Norway (GUSENLEITNER 1978, LÅG and STEINNES 1978). When judged according to the values presented by BERGMANN and NEUBERT (1976) the micronutrient contents reported in the present study are mainly to be classified as »normal». The boron contents were low in the wheats at both locations if the range 6—10 mg/kg at the heading stage is considered as the range of sufficiency. A relatively high manganese content was found in the winter wheat at Tikkurila if the values above 28 mg/kg at the heading stage are considered to be more than sufficient.

The micronutrient contents of wheats are generally in accordance with the extractable contents of soils. Exceptions are molybdenum in spring wheat and manganese in winter wheat which, when compared between growing locations, are opposite to the extractable contents of soils. In both cases the pH of the soil may essentially affect the availability.

There were only small differences in micronutrient contents between winter and spring wheats. The differences were also small between different varieties. This is in accordance with the investigations of CZARNOWSKA (1975) who reported very similar Cu, Fe, Mn and Zn contents in two winter wheat varieties.

The stage of growth of a plant has long been known to be a very important factor in determining the mineral content of the plant (e.g. BATES 1971). To obtain comparable results the sampling for plant analysis should be done at the same stage of plant growth. As stated above, the highest micronutrient contents as well as the most distinct differences due to soil nutrient status existed at an early stage of plant growth, i.e. at the tillering stage. Later, during the stem extension stage the contents as well as the differences decreased and reached their lowest values at the heading and ripening stages in late summer and early autumn. For example, the Cu content of spring wheat in early summer correctly reflects the respective extractable content in soil, while the plant content at later stages is likely to give a false picture of the Cu status of the soil.

Because of higher contents and more distinct differences in materials sampled at early stages, analytical errors have less bearing than in materials from later stages. Obviously the micronutrient contents of wheat plants at early stages also better reflect the micronutrient status of soils than analyses of plant material from later stages. Therefore the mid-tillering stage of wheat seems to be best suited for sampling.

In the study carried out by SIPPOLA et al. (1978), dealing with the macronutrients Ca, K, Mg and P, the best period for sampling was also found to be the tillering stage: occuring during the month of June for spring wheat and about two weeks earlier for winter wheat, in Finnish conditions.

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SELOSTUS

Vehnän mikroravinnepitoisuuksien muutokset kasvukauden aikana

TOIVO YLÄRANTA, HÅKAN JANSSON ja JOUKO SIPPOLA

Maatalouden tutkimuskeskus

Yhteensä neljällä koekentällä Tikkurilassa ja Mouhijärvellä kasvaneen kevät- ja syysvehnän B-, Cu-, Fe-, Mn-, Mo- ja Zn-pitoisuus analysoitiin kasvukauden aikana kahdesti viikossa. Tänä aikana B-, Cu- ja Fe-pitoisuus aleni huomattavasti: booripitoisuus alkukesän pitoisuudesta 4—12 mg/kg korjuuajan pitoisuuteen 2 mg/kg, kuparipitoisuus vastaavasti 6—10 mg/kg pitoisuuteen 3—4 mg/kg. Kevätvehnän rautapitoisuus aleni alkukesän pitoisuudesta 110—140 mg/kg korjuuajan pitoisuuteen 40—80 mg/kg. Tikkurilan syysvehnän Fe-pitoisuuden lasku oli selvästi suurempi, alkukesän pitoisuudesta 210 mg/kg korjuuajan pitoisuuteen 60 mg/kg. Muutokset vehnän sinkkipitoisuuksissa olivat pieniä. Muista mikroravinteista poiketen nousivat sen pitoisuudet kuitenkin hiukan koko kasvukauden ajan. Vehnän kasvukauden aikaiset Mn- ja Mo-pitoisuuksien vaihtelut eivät olleet yhtä selväpiirteisiä. Molybdeenipitoisuuksien erot olivat suurimmat vehnän aikaisessa kehitysvaiheessa. Mangaanipitoisuuksien erot olivat pienimmät keskikesällä, mutta suuret sekä kesän alussa että syksyllä.

Kevät- ja syysvehnän B-, Cu-, Fe-, Mn-, Mo- ja Zn-pitoisuuksien välillä ei havaittu selviä eroja. Mangaania ja molybdeeniä lukuunottamatta erot maasta uuttuneissa ravinnemäärissä heijastuivat vehnän vastaaviin pitoisuuksiin. Vehnän ravinnepitoisuuksien erot olivat yleensä huomattavasti suuremmat kasvin varhaisessa kehitysvaiheessa kuin kasvukauden lopulla. Arvioitaessa kasveille käyttökelpoisten mikroravinteiden määrää maassa kasvianalyysin avulla olisi näytteet otettava varhaisessa kasvuvaiheessa.

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Seria AGROGEOLOGIA ET -CHIMICA N. 95 — Sarja MAA JA LANNOITUS n:o 95

SOIL PHOSPHORUS TEST VALUES OBTAINED BY ACID AMMONIUM ACETATE, WATER AND RESIN EXTRACTION AS PREDICTORS OF PHOSPHORUS CONTENT IN TIMOTHY (PHLEUM PRATENSE L.)

JOUKO SIPPOLA and HÅKAN JANSSON

SIPPOLA, J. & JANSSON, H. 1979. **Soil phosphorus test values obtained by acid ammonium acetate, water and resin extraction as predictors of phosphorus content in timothy** (*Phleum pratense* L.). Ann. Agric. Fenn. 18: 225—230. (Agric. Res. Centre, Inst. Soil. Sci., SF-01300 Vantaa 30, Finland.)

Acid ammonium acetate (pH 4,65), water and anion-exchange resin soil test methods were compared with respect to their power to predict the phosphorus content in timothy. The 234 soil and timothy sample pairs of the study represented nine types of clay, coarse mineral and organic soils of Finland.

Acid ammonium acetate, water and resin extracted an average of 8,3, 5,3, and 7,5 mg phosphorus per litre soil, respectively, from all soils. The resin method extracted more phosphorus from clay and organic soils than the other methods. The water method resulted in the lowest values, but contents almost as high as those obtained with acid ammonium acetate were obtained from Carex peat soils.

The soil test methods explained 8—21 % of the variation in phosphorus content of timothy. None of the soil test methods was superior to the others in predicting the phosphorus content in timothy. Significant correlation between soil test values and timothy phosphorus content were obtained with all three methods for all major soil groups. Several soil and other factors, however, seem to cause variation in the availability and uptake of soil phosphorus which complicates the interpretation of soil phosphorus tests.

Index words: Soil testing, phosphorus extraction methods.

INTRODUCTION

Many soil testing methods have been developed to estimate the need for phosphorus fertilization in crop growing. In Finland the acid ammonium acetate extraction has been used for this purpose since its introduction (VUORINEN and MÄKITIE 1955). The method has been used extensively and over 100 000 soil samples are analyzed each year (KURKI 1972).

Many other soil tests for phosphorus have been proposed since the development of the acid ammonium acetate method. One of the new methods which has been claimed to show promising results in testing for soil phosphorus is the water extraction used in the Netherlands (van der PAAUW 1971). This method has been found to be better than the popular ammonium lactate method and it has been found to be suitable for various types of soils (Ris and van Luit 1973).

Another method which has proved to be successful is the anion-exchange resin extraction (e.g. Cooke and Hislop 1963). The use of this method has not been extensive because of time-consuming and difficult analytical procedures. However, various modifications have been proposed to make this method more easily applicable (Sibbesen 1977, Aura 1978 a).

The purpose of the present study was to obtain some information under Finnish conditions on the suitability of the water and resin extraction methods for soil phosphorus compared to the acid ammonium acetate method currently in use in Finland.

MATERIAL AND METHODS

The soil and plant samples of this study (234 pairs, Table 1) were part of a series which covered the whole of Finland (Sippola and Tares 1978, Kähäri and Nissinen 1978).

The phosphorus was extracted from soils with acid ammonium acetate (pH 4,65) according to the method of Vuorinen and Mäkitie (1955). The water extraction was carried out according to Sissingh (1971); 4,3 ml soil was measured and moistened with 7 ml deionised water, allowed to stand for 22 h after which 250 ml water was added and shaken for 1 h. In the case of turbid filtrates, NaCl was added to coagulate the clay as proposed by Sissingh (1971).

For the resin extraction 100 ml water was added to 10 ml soil into a bottle and then allowed to stand for 0,5 h. For the exchange, 5 g anion-exhange resin (Dowex 21K) in chloride form was used. Eluation of phosphorus was carried out after extraction with 100 ml 1 M HCl for two hours. The phosphorus concentration of the eluate was determined by the method of Watanabe and Olsen (1965).

The pH values reported were measured in a 1:2,5 v/v water suspension. The organic carbon was determined using a modification of the colorimetric dichromate combustion method (Graham 1948).

RESULTS

Amounts of phosphorus extracted from soils.

The acid ammonium acetate extracted phosphorus was an average of 8,3 mg/litre soil from all soils. The extracted contents for the water and resin methods were 5,3 and 7,9 mg/l soil, respectively, which were 64 and 95 % of that extracted with acid ammonium acetate. The range of the extracted phosphorus contents was 0,9—81 mg/l with acid ammonium acetate. With water and resin the ranges were 0—40 mg/l and 0—66 mg/l, respectively.

The least phosphorus extracted with the resin method was from soils in the silty clay group (Table 1). Little phosphorus was extracted from soils in the silt and finer finesand groups with the resin method. The largest difference in the amount of extracted phosphorus by the acid ammonium acetate and water methods was in the group of silt soils where the water extracted only 40 % of the phosphorus solubilized by acid ammonium acetate. Of the Carex peat soils, acid ammonium acetate and water extracted almost similar contents.

The resin method extracted more phosphorus from clay and organic soils than acid ammonium acetate or water. From coarse-textured mineral soils the resin method extracted more phosphorus than water but less than acid ammonium acetate.

Table 1. Soils, their mean values of pH, organic carbon, soil phosphorus extractable with acid ammonium acetate, water and anion exchange resin, and content of phosphorus in timothy.

Soil type	n	pH	org. C	P mg/l soil			P in timothy mg/kg
				Acid amm.-acet.	Water	Resin	
Heavy clay	14	5,8	4,3	7,8	6,1	8,0	2 684
Sandy clay	14	5,7	4,2	9,8	7,9	12,4	2 724
Silty clay	25	5,6	4,7	4,8	3,0	6,1	2 755
Clay soils	53	5,7	4,5	6,9	5,1	8,3	2 728
Silt	30	5,7	3,3	7,5	3,0	5,1	2 771
Finer finesand ..	32	5,7	3,3	7,1	3,2	5,1	2 881
Finesand	35	5,7	3,8	7,5	3,9	6,2	2 722
Glacial till	26	5,9	3,5	12,5	5,3	6,4	2 972
Coarse mineral soils	123	5,7	3,5	8,5	3,8	5,7	2 828
Mull	33	5,3	16,1	5,6	4,2	7,9	2 929
Carex peat	25	5,1	33,5	14,4	14,1	18,4	3 073
Organic soils	58	5,2	23,6	9,4	8,5	12,4	2 991
Whole material	234	5,6	8,6	8,3	5,3	7,9	2 846

Correlation of the extracted phosphorus with soil pH, soil organic C and phosphorus in timothy.

Soil pH appeared to be more important in mineral soils than in organic soils for phosphorus extractability (Table 2). The effect of soil organic matter on extractability was significant only in organic soils. The correlation coefficients indicate that from 8 to 21 % of variation in timothy phosphorus content was explained by variation in soil test values. The correlation coefficients differed little between extraction methods and the existing differences were not significant.

The calculation of logarithmic regressions increased the values of the correlation coefficients in most cases (Fig. 1).

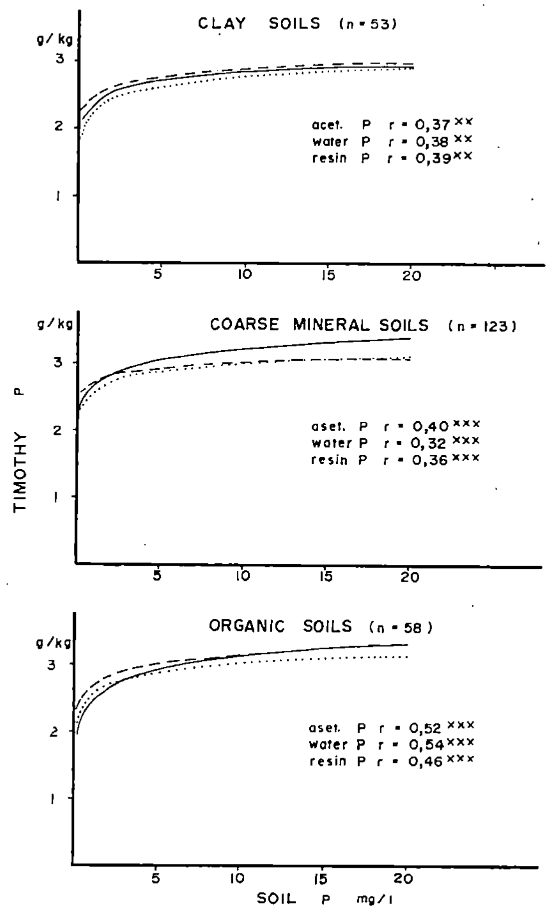

Fig. 1. The logarithmic regressions (y = a+logx) between soil phosphorus test values and phosphorus content of timothy. ——— = acid ammonium acetate-P. -------- = water-P and ······ = resin-P.

Table 2. Linear correlations of soil pH, soil organic carbon and phosphorus content in timothy with soil phosphorus determined by acid ammonium acetate, water or resin extraction (coefficients of log. correlations in parentheses).

	Clay soils n = 53	Coarse mineral soils n = 123	Organic soils n = 58
pH — acid amm. acet. P	0,37***	0,39***	—0,12
pH — water P	0,33*	0,27***	—0,28*
pH — resin P	0,28*	0,22***	—0,18
org. C — acid amm. acet. P	—0,20	—0,02	0,48***
org. C — water P	—0,20	0,05	0,55***
org. C — resin P	—0,20	0,13	0,45***
Timothy P — acid amm. acet. P ..	0,28* (0,37**)	0,35*** (0,40***)	0,39** (0,52***)
Timothy P — water P	0,29* (0.38**)	0,39*** (0,32***)	0,46*** (0,54***)
Timothy P — resin P	0,32* (0,39**)	0,39*** (0,36***)	0,39** (0,46***)

DISCUSSION

The amount of soil phosphorus extracted with acid ammonium acetate from the samples in the heavy clay group was on average almost twice the amount of 4,9 mg/litre soil determined in a larger series of 40 samples (SIPPOLA and TARES 1978). The differences in other soil groups in comparison with the above study were smaller, and in the case of Carex peats the mean values were almost identical, 14,4 and 14,6 mg/l, respectively.

The mean phosphorus content of all samples determined by water extraction was 5,3 mg/l. This is much lower than contents determined in Dutch soils which ranged from 3—33 mg/l with an average of 15 mg/l (van der PAAUW 1971). With a different water extraction method (1:40 soil-water ratio) much higher phosphorus contents with a mean of 19 mg/l soil have been obtained for 30 Finnish soils (AURA 1978 a). These 30 soils were collected only from southern Finland and heavily fertilized sugar beet fields were also included.

No comparable results exist for the resin extraction method. However, with a slightly different resin extraction method, contents in the same range as in the present study have been reported in Finnish soils (AURA 1978 a).

The methods used in this study extract a relatively easily soluble phosphorus fraction from soils. For example, the widely used ammonium lactate method extracts 4 to 17 times higher amounts than acid ammonium acetate extraction from Finnish soils (BARKOFF and OHLANDER 1967). The acid ammonium acetate solubilizes iron and aluminium phosphates to a very limited extent (VUORINEN and MÄKITIE 1955). According to MÜNK and BÄRMANN (1971) the phosphorus contained in the water extract includes no other important soil phosphorus form than that in soil solution. In resin extraction aluminium and iron phosphates are dissolved to some extent, but the limiting factor is the rate of diffusion of phosphate from the porous soil aggregates rather than the exchange of phosphorus by resin (AURA 1978 b). Factors determining the rate of desorption of phosphates from soil to water face include the chemical composition of the water face and the anionic form of the resin. A somewhat closer correlation has been found between phosphorus uptake and phosphorus extracted by the bicarbonate form of the resin rather than the chloride form which was used in this study (SIBBESEN 1978). The basis for closer correlation is assumed to be that the bicarbonate form of the resin produces a similar environment in suspension to that which growing plants create in the rizosphere. The use of the bicarbonate form of the resin might also have improved the results of the present study.

A good property of the water extraction method has been claimed to be its non-sensitivity towards variation in soil properties (van der PAAUW 1971). The correlation coefficients obtained between the results of the extraction methods and pH or organic carbon do not show significant differences between methods in this respect.

The yield increase is usually taken as a criterion of crop response in judging the reliability of a soil test method. However, the results of the water extraction method have been claimed to be in good correlation with the phosphorus content of potato shoots (RIS and van LUIT 1973). Van der PAAUW (1971) reported that wheat phosphorus content was in better correlation than wheat yield with soil phosphorus extracted with water. In the present study no yield data was available for timothy samples. Therefore it is not possible to produce any information in this respect.

In pot experiments where growth factors are under better control than in field experiments, it is possible to obtain a high degree of explanation between soil test and crop response. As much as 80—90 % of the variation in phosphorus contents or uptake can be accounted for by the soil phosphorus test value in such experiments (AURA 1978 a, SIBBESEN 1978). Relatively good correlations are obtained even in field experiments where a wide range in the factor under investigation is arranged (MUNK and BÄRMANN 1971).

Much lower coefficients of correlation usually result when sample material is collected from farmers' fields as was done in the present study (SILLANPÄÄ and LAKANEN 1969, KÄHÄRI and NISSINEN 1978). When the explained variation ranged from 11 to 36 % in the cases of significant correlations the result cannot be regarded as exceptionally low, especially when dealing with phosphorus.

It may be concluded that no single method studied proved to be significantly better than the others in predicting the phosphorus content in timothy. Evidently, it appears to be difficult to develop a decisively better method, and this may be due to the fact that there are very many factors other than the soil phosphorus content indicated by a test value which affect the uptake of phosphorus and growth of plants. It is also understandable that a quick test cannot sufficiently describe the uptake of phosphorus by a plant during a whole growing period with variable weather conditions.

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SELOSTUS

Happamalla ammoniumasetaatilla, vedellä ja ioninvaihtohartsilla uutettujen maan fosforipitoisuuksien korrelointi timotein fosforipitoisuuden kanssa.

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Maatalouden tutkimuskeskus

Maan kasveille käyttökelpoisen fosforin määrittämiseen käytettyjä menetelmiä pyrittiin vertailemaan 234 maa- ja kasvinäyteparia käsittävän aineiston puitteissa. Aineisto jakautui kolmeen savimaaluokkaan, neljään karkean kivennäismaan luokkaan ja kahteen eloperäisten maiden luokkaan, joihin tuli 14—35 näyteparia kuhunkin. Uuttomenetelminä olivat Suomessa käytössä oleva hapan ammoniumasetaatti, Hollannissa kehitetty ja käytetty vesiuutto sekä anioninvaihtohartsi, jonka rutiinikäyttöön tuloa hidastaa muita hankalampi suoritus.

Hapan ammoniumasetaatti uutti kaikista näytteistä keskimäärin 8,3 mg fosforia litrasta maata, määrien vaihdellessa 0,9—81 mg/l. Vesi- ja hartsiuuttomenetelmät antoivat tuloksiksi 5,3 ja 7,5 mg/l vaihteluvälien ollessa vastaavasti 0—40 ja 0—66 mg/l. Hapan ammoniumasetaatti uutti fosforia karkeista kivennäismaista enemmän kuin muut menetelmät. Hartsin savi- ja eloperäisistä maista uuttamat fosforimäärät olivat muiden menetelmien tuloksia suuremmat. Vesiuutolla saatiin kaikkein alhaisimmat tulokset veden uuttaessa maasta vain kaikkein helppoliukoisimman fraktion.

Timotein fosforipitoisuuden ja kaikilla uuttomenetelmillä saatujen maan fosforipitoisuuksien välillä oli varma riippuvuussuhde. Maa-analyysi selitti 8—21 % timotein fosforipitoisuuden vaihtelusta.

Varmaa eroa eri maa-analyysimenetelmien välillä ei voitu todeta. Tulosten mukaan näyttää ilmeiseltä, että millään yksinkertaisella maa-analyysimenetelmällä ei voida ennustaa kasvien fosforin saantia kovin tarkkaan, koska useat tekijät määräävät kasvien fosforin oton.

ANNALES AGRICULTURAE FENNIAE VOL. 18: 231—245 (1979)

Seria AGROGEOLOGIA ET -CHIMICA N. 96 — Sarja MAA JA LANNOITUS n:o 96

THE EFFECT OF NITROGEN FERTILIZER ON THE POTASSIUM REQUIREMENT OF GRASSLAND FOR SILAGE

HILKKA TÄHTINEN

TÄHTINEN, H. 1979. **The effect of nitrogen fertilizer on the potassium requirement of grassland for silage.** Ann. Agric. Fenn. 18: 231—245. (Agric. Res. Centre, Inst. Agric. Chem. and Phys., SF-01300 Vantaa 30, Finland.)

Field experiments covering 2—3 years were carried out to study the effect of nitrogen fertilizer on the potassium fertilizer requirement of grass or of grass-dominated silage leys. Twelve experiments were conducted in various parts of Finland between latitudes 61 and 66 °N. The crops were harvested twice at the silage stage. Both cuts were treated with nitrogen (50, 100 or 200 kg/ha) and potassium (50 or 100 kg/ha). Basic fertilizer containing phosphorus was spread on the fields in spring each year.

Increasing the amount of nitrogen fertilizer used from 50 to 100 kg/ha/cut produced an increase of around 25 % in the dry matter yield. The highest amount of nitrogen fertilizer used produced no further increase in the yield, although it increased the nitrogen content to the extent that the crude protein yield increased by a further c. 25 %.

A plentiful supply of nitrogen fertilizer led to a considerable reduction in the amount of clover on clover-grass leys. Even the minimum amount of nitrogen used (50 kg/ha/cut) reduced the clover content of the stand. Increasing the amount of potassium fertilizer did not improve clover survival on grassland.

The difference in dry matter yield brought about by potassium was significantly dependent upon the acid ammonium acetate-extractable potassium content of the soil only when 100 kg/ha/cut or more of nitrogen fertilizer was used. In this case an increase in the amount of potassium fertilizer used on soils with a low potassium content brought about an increase in yield. The amount of potassium fertilizer used did not significantly affect the crude protein yield.

Increasing the amount of potassium fertilizer used increased the potassium content of the crop. This also applied to nitrogen fertilizer, providing the plants had a sufficient supply of potassium. It was possible to prevent an increase in the potassium content both by dividing the potassium between the crops from different cuts and by laying greater emphasis on the use of potassium fertilizer on older fields.

The acid ammonium acetate-extractable potassium content of the soil remained virtually unchanged when 50 kg/ha/cut of nitrogen was used and increased slightly for 100 kg/ha/cut of nitrogen when the N : K ratio was 1. Use of the maximum amount of nitrogen (N : K = 2) caused a further increase in the potassium content of the soil.

Index words: Nitrogen, potassium, grassland for silage.

INTRODUCTION

A number of field experiments carried out in Finland show that it is possible, using large amounts of nitrogen fertilizer, to produce large quantities of crude protein-rich fodder (SALONEN et al. 1962, JÄNTTI and KÖYLIJÄRVI 1964. HIIVOLA et al. 1974).

There are, however, certain drawbacks to the use of large amounts of nitrogen. Grass stands often take up more potassium from the soil than they require for growth. The potassium content of the fodder may even be high enough to cause problems, especially in the early summer cuts (MELA et al. 1977). Extensive use of nitrogen fertilizer thus greatly reduces the potassium reserves of the soil (JOY et al. 1973).

Some studies have shown that the use of large quantities of nitrogen fertilizer on the last cut of the growing season on grasslands lowers the water-soluble carbohydrate content of the roots and stubble of the grass, and thins out the stand the following spring (PÁLMASON 1970, HUOKUNA and HIIVOLA 1974). Winter damage is common, especially in northern Finland, where the need for renewal of grasslands has become considerably more urgent due to the increasing use of fertilizers.

The aim of this study is to examine, using a large amount of nitrogen fertilizer, the effect of increasing the quantity of potassium fertilizer on size and nutrient content of fresh fodder, and to establish to what extent potassium fertilizer can be used to prevent the detrimental effects of large amounts of nitrogen fertilizer.

MATERIAL AND METHODS

The experimental series comprises 12 experimental fields on farmlands in various parts of Finland. The sites are on various types of clay, fine sand and Carex peat soils with different nutritional contents (Table 1).

The experiments are based on first or second-year grass leys or grass-dominated leys. All these were harvested twice since it is not usually possible to harvest three times in northern Finland. Harvesting was carried out at the silage stage, i.e. at the stage of early heading of timothy grass. In some of the experiments growth had progressed slightly further. The growth level of the stand was less uniform in the second cut than in the first.

The treatments were three different nitrogen levels: $N_1 = 100$, $N_2 = 200$ and $N_4 = 400$ kg/ha/year with two potassium levels for each: $K_1 = 100$ and $K_2 = 200$ kg/ha/year. Nitrogen was applied in the form of ammonium nitrate limestone (26 % nitrogen and 2,7 % magnesium) and potassium in the form of potassium chloride (50 % potassium). Half the nitrogen and half the potassium were topdressed at the beginning of the growing season and the other half applied immediately after the first cut. Basic treatment with 70 kg/ha of superphosphate (8,7 % phosphorus) was given to all the plots in spring for

Table 1. The soils and the results of soil tests in different experiments.

Trial no.	Soil	$pH_{(H_2O)}$	mg/l of soil				Ratio K/Mg
			Ca	K	P	Mg	
1	Loam	7,2	4 640	252	89,6	88	2,9
2	Heavy clay ..	5,3	1 900	158	8,1	439	0,4
3	Silty clay ...	6,6	1 975	272	25,0	115	2,4
4	Sandy clay ..	5,5	840	98	3,1	149	0,7
5	Carex peat ..	5,6	1 240	118	13,2	292	0,4
6	Carex peat ..	5,1	1 100	66	26,1	93	0,7
7	Finer fine sand	6,2	1 270	200	8,0	41	4,9
8	Silt	5,8	1 425	98	13,7	180	0,5
9	Fine sand ...	5,9	610	92	3,2	22	4,2
10	Fine sand ...	5,8	1 010	78	12,6	181	0,4
11	Silty clay ...	5,5	1 075	128	12,1	183	0,7
12	Carex peat ..	5,0	1 560	45	8,8	390	0,1

the entire growing season. The experiment was set up using four replicates with randomized blocks. Eight of the experiments (1—8) were continued in the same place for three years and four experiments (9—12) for two years.

The botanical composition and dry matter content of the crop were determined. The total nitrogen and trace element contents of timothy grass, and of meadow fescue (in experiment 3) were determined. In the case of red clover, these contents were determined only when the species accounted for more than 5 % of the stand. The crude protein content of the crops (6,25 x nitrogen content) was calculated. The risk of grass tetany due to the quality of fodder is represented by the cation equivalent ratio K/(Ca+Mg).

Samples of the soil were taken before spreading the fertilizers. The soil $pH_{(H_2O)}$ was determined, together with the nutrients extractable into acid ammonium acetate according to Vuorinen and Mäkitie (1955; Kurki et al. 1965) (Table 1). At the end of the experimental period the changes brought about in these values due to the nitrogen and potassium fertilizers were investigated in six experiments.

Variance, correlation and regression analyses were used to test the significance of the results at the 95 % (*) and 99 % (**) levels of probability.

RESULTS AND DISCUSSION

Dry matter yield

Increasing the amount of nitrogen used in the experiments from 50 to 100 kg/ha/cut almost without exception raised the yield in both cuts (Table 2). The annual dry matter yield increased on average by one quarter (Fig. 1). However, in only a small number of experiments did raising the amount of nitrogen from 100 to 200 kg/ha/cut produce a significant increase in yield. Nitrogen fertilization had a pronounced effect also in experiments 1 and 2, which contained large amounts of red clover. This is in agreement with the results of earlier studies (Raininko 1968). The difference in yield due to the use of different amounts of potassium fertilizer in the present study was seldom significant. The interaction between nitrogen and potassium was significant only in some experiments.

Earlier studies have shown that dividing the nitrogen fertilizer between each cut greatly increases the dry matter yield. Sharing the potassium fertilizer, on the other hand, has no significant effect (Mela et al. 1977).

All the experiments in the present study involved treatment with potassium fertilizer. The average increase in yield brought about by potassium varied, depending on the amount of acid ammonium acetate-extractable potassium in the soil, only at the higher nitrogen levels (r_{N1} = -0,17, r_{N2} = -0,71* and r_{N4} = -0,67*). The dependence of the effect of potassium on the amount of nitrogen fertilizer used has also been confirmed by Hernes (1978). Application of 50 kg/ha/cut of potassium (N:K=1) was sufficient when small amounts of nitrogen fertilizer were used as well as with larger amounts of nitrogen providing the soil had a reasonable potassium content.

The magnesium content of the soil had no significant contribution to clarifying the variations in the average differences in yield using potassium. This was also found by Keränen and Tainio (1967) in their research. It should be pointed out that the nitrogen fertilizer used in both this and the present study contained more magnesium than the crop took up. Despite this, the average change in yield due to potassium in the present study was just as dependent on the ratio between the potassium and magnesium contents of soil (mg/l) (r = -0,69*) as on the potassium content of soil alone (r = -0,70*).

Table 2. The effect of nitrogen and potassium fertilizers on the dry matter yield (kg/ha) of 1st and 2nd cut and total.

Trial no.	Year	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	Significances				N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	Significances				N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	Significances			
		1st cut						N_{1-2}	N_{1-4}	N_{2-4}	K_{1-2}	2nd cut						N_{1-2}	N_{1-4}	N_{2-4}	K_{1-2}	Total						N_{1-2}	N_{1-4}	N_{2-4}	K_{1-2}
1	1	2 550	2 536	3 046	3 613	2 876	2 394					..	..	..	..	..	..					..	..	..	..	..	..				
	2	2 894	2 894	2 746	2 750	2 758	2 818					3 438	3 651	5 032	4 701	5 257	4 917					6 333	6 545	7 778	7 451	8 017	7 736				
	3	4 114	3 944	4 514	4 089	4 182	4 284					3 647	4 182	4 854	4 811	5 041	4 684					7 761	8 126	9 366	8 900	9 222	8 968				
		3 186	3 125	3 435	2 484	3 272	3 165					3 543	3 917	4 943	4 756	5 149	4 801	**	**			7 047	7 336	8 572	8 176	8 620	8 352	**	**		
2	1	2 924	3 311	3 927	3 511	3 778	3 540					608	761	867	888	1 046	944					3 532	4 072	4 794	4 399	4 824	4 485				
	2	3 875	3 838	4 138	4 225	3 862	3 600					1 937	2 125	2 313	2 600	3 000	2 625					5 812	5 962	6 451	6 825	6 863	6 225				
	3	1 811	1 717	2 508	2 627	3 120	3 086					1 131	1 150	1 483	1 386	1 598	1 301					2 941	2 867	3 995	4 012	4 718	4 387				
		2 870	2 955	3 524	3 454	3 587	3 409	*	*			1 225	1 345	1 556	1 625	1 881	1 623	*	**			4 095	4 300	5 080	5 079	5 468	5 032	**	**		
3	1	3 018	3 094	3 910	3 765	4 297	4 127					1 696	1 734	1 870	1 950	2 270	2 253					4 714	4 828	5 780	5 746	6 566	6 379				
	2	4 665	4 866	5 525	5 589	5 090	4 866					3 879	3 878	5 812	5 430	6 715	6 184					8 544	8 744	11 337	11 018	11 805	11 051				
	3	2 261	2 219	3 621	2 907	3 919	3 927					1 029	1 080	2 049	1 930	1 862	2 338					3 290	3 299	5 670	4 837	5 781	6 265				
		3 315	3 393	4 352	4 087	4 435	4 307	**	**			2 201	2 231	3 244	3 103	3 616	3 592					5 516	5 624	7 596	7 200	8 051	7 898				
4	1	2 019	2 179	2 508	2 699	2 954	2 848					1 159	1 445	2 954	3 379	4 559	3 995					3 178	3 624	5 462	6 078	7 513	6 843				
	2	4 144	4 165	4 473	4 814	4 516	5 600					2 604	2 412	3 305	3 698	3 358	4 070					6 748	6 577	7 778	8 512	7 874	9 670				
	3	2 933	3 324	3 417	3 698	4 301	4 403					2 295	2 202	3 001	3 349	3 349	3 791					5 228	5 526	6 418	7 047	7 650	8 164				
		3 032	3 223	3 466	3 737	3 924	4 284	**	**	**	*	2 019	2 020	3 087	3 475	3 755	3 952	**	**			5 051	5 242	6 553	7 212	7 679	8 226	**	**	*	
5	1	2 423	2 603	2 880	2 890	3 092	3 145					2 264	2 465	3 400	2 975	3 390	3 613					4 687	5 068	6 280	5 865	6 482	6 758				
	2	1 700	1 711	1 870	1 796	1 169	1 403					2 678	2 582	2 826	2 763	2 635	2 784					4 378	4 293	4 696	4 559	3 804	4 187				
	3	1 751	1 887	1 632	1 539	1 131	1 071					2 006	2 873	3 128	3 315	3 035	2 848					3 757	4 760	4 760	4 854	4 166	3 919				
		1 958	2 067	2 127	2 075	1 797	1 873					2 316	2 640	3 118	3 018	3 020	3 082	*	*			4 274	4 707	5 245	5 093	4 817	4 955				
6	1	2 171	2 116	2 402	2 578	2 356	2 421					3 345	3 419	3 641	3 899	3 825	3 641					5 516	5 535	6 043	6 477	6 181	6 062				
	2	2 176	1 717	1 556	2 304	1 913	1 700					2 312	2 091	2 185	3 664	2 890	3 426					4 488	3 808	3 741	5 968	4 803	5 126				
	3	4 165	3 443	4 055	3 528	3 876	3 749					1 632	1 683	1 573	1 794	2 066	2 338					5 797	5 126	5 628	5 322	5 942	6 087				
		2 837	2 425	2 671	2 803	2 715	2 623					2 430	2 398	2 466	3 119	2 927	3 135		*			5 267	4 823	5 137	5 922	5 642	5 758				

7	1	2 329	2 763	2 601	2 482	2 686	2 584					4 870	4 862	8 066	6 231	6 817	6 664					7 199	7 624	10 667	8 713	9 503	9 248				
	2	3 213	3 485	4 191	4 089	3 740	3 689					2 797	2 746	3 468	3 681	3 655	3 494					6 010	6 231	7 659	7 770	7 395	7 183				
	3	6 120	6 443	7 072	6 766	6 562	6 239					2 057	1 879	3 460	3 349	4 531	3 978					8 177	8 322	10 532	10 115	11 093	10 217				
		3 887	4 230	4 621	4 446	4 329	4 171	*				3 241	3 162	4 998	4 420	5 001	4 712	**	**			7 129	7 392	9 619	8 866	9 330	8 883	**	**		
8	1	3 036	3 008	3 314	3 186	3 375	3 392					1 287	1 476	2 123	2 060	1 995	1 856					4 323	4 484	5 437	5 246	5 370	5 248				
	2	2 356	2 279	2 669	2 732	2 738	2 330					2 092	2 295	3 784	4 017	3 923	5 289					4 448	4 574	6 453	6 749	6 661	7 619				
	3	4 047	4 043	5 155	5 150	4 737	4 927					1 635	1 589	2 863	4 120	2 494	2 935					5 682	5 632	8 018	9 270	7 231	7 863				
		3 146	3 110	3 713	3 689	3 617	3 550	**	*			1 671	1 787	2 923	3 399	2 804	3 360	**	**			4 818	4 897	6 636	7 088	6 421	6 910	**	**		
9	1	3 797	4 094	4 718	4 703	4 378	4 193					4 009	3 400	5 128	5 072	5 922	6 177					7 806	7 494	9 846	9 775	10 300	10 370				
	2	2 791	2 890	3 386	3 797	3 145	3 117					3 145	3 542	4 661	3 853	4 094	3 556					5 936	6 432	8 047	7 650	7 239	6 673				
		3 294	3 492	4 052	4 250	3 762	3 655	**	*	**		3 577	3 471	4 895	4 463	5 008	4 867					6 871	6 963	8 947	8 713	8 770	8 522	**	**		
10	1	2 508	2 656	3 039	3 103	3 443	3 709					2 390	2 370	2 869	2 614	2 412	2 476					4 898	5 026	5 908	5 717	5 855	6 185				
	2	2 391	2 264	2 944	3 188	2 423	2 954					2 444	2 720	3 400	3 018	3 326	3 815					4 835	4 984	6 344	6 206	5 749	6 769				
		2 450	2 460	2 992	3 146	2 933	3 332	*	*			2 417	2 545	3 135	2 816	2 869	3 146					4 867	5 005	6 126	5 962	5 802	6 477	**	**		
11	1	3 464	4 101	4 049	4 293	4 346	4 452					3 506	3 964	4 559	4 664	4 803	5 536					6 970	8 065	8 608	8 957	9 149	9 988				
	2	2 049	2 236	2 525	2 236	2 491	2 202					2 474	2 890	3 944	3 987	4 930	4 420					4 523	5 126	6 469	6 223	7 421	6 622				
		2 757	3 169	3 287	3 465	3 419	3 327					2 990	3 427	4 252	4 326	4 867	4 978					5 747	6 596	7 539	7 590	8 285	8 305	**	**		
12	1	2 831	3 120	2 975	3 698	3 596	4 505					3 171	3 451	3 596	3 308	2 873	3 154					6 002	6 571	6 571	7 506	6 469	7 659				
	2	3 570	3 545	3 995	4 352	3 961	4 726					2 593	2 652	3 222	3 358	2 397	3 171					6 163	6 197	7 217	7 710	6 358	8 097				
		3 201	3 333	3 485	4 025	3 779	4 616		**		**	2 882	3 052	3 409	3 583	2 635	3 163	*		**	*	6 083	6 384	6 894	7 608	6 414	7 878	*	*		**

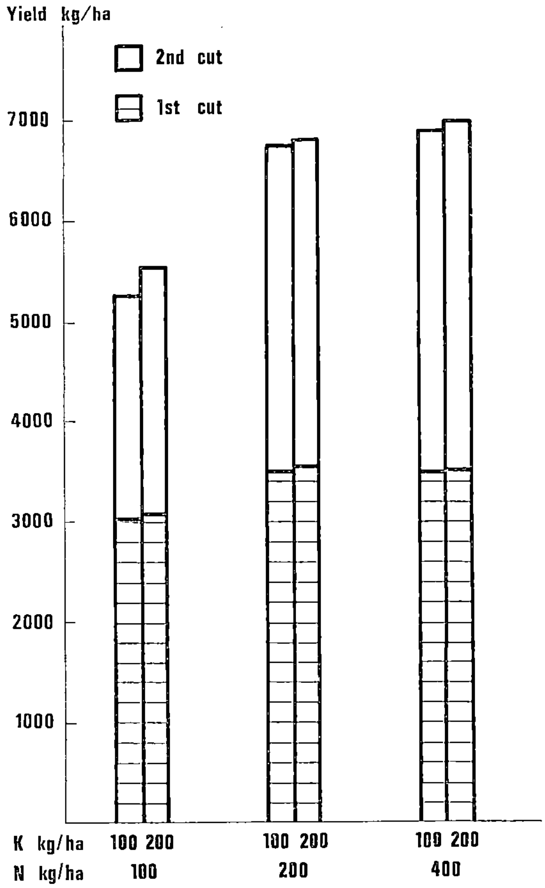

Fig. 1. Annual effect of nitrogen and potassium fertilizers on the dry matter yield (kg/ha) of silage grassland.

In some studies the K/Mg ratio was considered a better measure of the potassium requirement than the potassium content of soil (Hahlin 1973, Håland 1974), or else the ratio was recommended for use as a test value alongside the potassium content of soil (Johansson and Hahlin 1977).

In the present experiments, using 100 or 200 kg/ha/cut of nitrogen usually produced a greater average difference in yield for the different amounts of potassium if the soil K/Mg ratio was less than 1; on the other hand, there was a fall in yield if the ratio exceeded 2 (r_{N2} = -0,71* and r_{N4} = -0,67*). For the lowest nitrogen level the dependence was not significant (r_{N1} = -0,04). Criticism of the suitability of the plant's nutrient content as a measure of the fertilizer requirement has been mainly on the grounds that the nutrient content is greatly dependent on the stage of development of the plant. In addition, plant analyses often fail to provide the necessary information for the fertilizer to be used in time for the growing season in question. The ratio between the potassium and magnesium contents of timothy grass provided a better indication of the need to increase the amount of potassium fertilizer used on this particular species (r = -0,81**) than did the plant's potassium content (r = -0,48). The contents of the first cut for 50 kg/ha/cut of potassium and 100 kg/ha/cut of nitrogen were used in the comparison. Of the amounts of nitrogen used in the experiments 100 kg/ha/cut corresponded most closely to the quantity used in spring on Finnish grasslands. In these experiments the potassium content was usually in excess of 22 mg/g of dry matter, a value that is considered sufficient for the formation of a heavy yield. Since in the experiments discussed here the magnesium was in the nitrogen fertilizer and the need for potassium was linked with the amount of nitrogen fertilizer used it was not possible to determine precisely the significance of magnesium for the plant's uptake of potassium.

Botanical composition

Most of the experiments were based on timothy-grass dominated grass leys. Only in experiment 3 was the species cultivated meadow fescue. Experiments 1 and 3 were the ones in which the stand had the greatest amounts of red clover (Table 3); experiments 2 and 7 also contained small amounts of this species.

The proportion of red clover diminished markedly along with the cuts, and the larger the amount of nitrogen fertilizer used, the greater the decrease. This was accompanied by a marked increase in the proportion of grass species (Salo-

Table 3. The effect of nitrogen and potassium fertilizers on the red clover content (%) of the yield in experiments 1 and 3.

Trial no.	Year	Cut	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2
1	1	1	32,3	32,8	22,6	18,5	26,5	20,1
		2	..	..	..	..	..	..
	2	1	14,5	17,5	26,0	15,1	18,8	17,7
		2	5,5	3,2	1,4	1,6	0,9	1,3
	3	1	0,4	0,6	0,2	0,2	0,1	0,2
		2	1,2	0,3	0,6	0,7	0,4	0,5
3	1	1	30,5	24,1	16,0	18,1	13,1	11,5
		2	18,8	19,3	8,2	6,0	6,3	8,3
	2	1	10,0	12,3	4,4	3,3	1,5	1,2
		2	5,1	9,4	1,3	1,0	0	0
	3	1	0,2	0,3	0,1	0	0	0
		2	3,9	1,4	0	0	0	0

NEN et al. 1962, RAININKO 1968). There was a drastic reduction in the proportion of red clover in the stand as early as the second cut of the first year, since 50 kg/ha/cut of nitrogen promoted the growth of grass species in the stand and reduced the ability of red clover to compete. The reduction in the proportion of red clover was more marked in mixed stands than in those containing purely red clover (SALONEN and HIIVOLA 1963, RAININKO 1968, JULEN 1974).

In the present experiments potassium fertilizer had no significant effect on the composition of the stand or on the survival of red clover on grassland (cf. SALONEN and TAINIO 1961, HERNES 1978).

Wintering of leys

A number of experiments showed injury to the stands in spring in the second and third years of the experiment. No precise stand estimates were made to see how the stands had thinned out. The extent of damage to stands increased rapidly with increasing amounts of nitrogen. Earlier studies have shown that while large amounts of nitrogen fertilizer applied to the last crop of the growing season increase growth, they also lower the water-soluble carbohydrate content of the roots and the stubble and reduce the sward density the following spring (PÁLMASON 1970 a, HUOKUNA and HIIVOLA 1974, JONSSON 1976). In view of this the height of the stubble and the time of harvesting of the final cut usually have a pronounced effect on winter survival, especially in northern areas (SVENSSON 1974). Cutting sufficiently early allows the plant time to replenish its store of carbohydrate, used up in the growth that has started, before the arrival of winter. The detrimental effect of having to postpone harvesting can be allayed by cutting the stubble to a greater height than normal. On the other hand, a shortage of nitrogen may also adversely affect winter survival (JONSSON 1976).

Potassium is considered to be an important element in carbohydrate synthesis and accumulation in plants. An increase in the plant's sugar content lowers the freezing point of the cells. Thus in some experiments a plentiful supply of potassium improved the plant's physical hardiness and resistance to damage by frost (ADAMS and TWERSKY 1960, PÁLMASON 1970). However, the results obtained from experiments carried out under different growing conditions vary. In the present study the quantity of potassium fertilizer used did not appear to have any significant effect on the thinning of stands.

Nutrient content of the plants

Nutrient contents were determined from the yields of each cut for each of the experiments. The results of individual experiments concerning the plant nutrient contents and uptake of nutrients have been published in Finnish (TÄHTINEN 1979).

The changes in the nutrient contents of the crop brought about by the use of fertilizer are similar to those obtained in earlier studies carried out in Finland on grass and silage grass leys, bearing in mind the fact that the present study did not contain individual experiments completely without nitrogen or potassium fertilizer (Salonen and Tainio 1961, Salonen et al. 1962, Salonen and Hiivola 1963, Mäntylahti and Marjanen 1971, Rinne et al. 1974, Mela et al. 1977). In the following the contents are given in mg/g of dry matter. The nutrient contents obtained for timothy grass and red clover for different treatments show considerable variations from year to year and from one experimental field to another.

In the following the figures are examined mainly with respect to the yield formation, with particular attention to variations in potassium content of the crop. From the point of view of feed for livestock it should be pointed out that some of the nutrients are lost along with the press juice of silage; on the other hand, mineral supplements can be used to satisfy the mineral requirements of animals.

Timothy

The nitrogen content of timothy increased considerably and in direct proportion to the amount of nitrogen fertilizer used; in the first cut the average increase was 0,6 mg/g and in the second cut 0,7 mg/g for each 10 kg of nitrogen in the fertilizer. The corresponding figures for the crude protein content were 3,8 and 4,4 mg/g. Use of potassium fertilizer did not usually have any effect on the nitrogen content of the forage. The interaction of potassium and nitrogen was significant in only one of the experimental crops.

Only rarely and under certain conditions has extensive use of nitrogen fertilizer been shown to increase the nitrate content to an undesirable level (Baerug 1977). Compared with the other species of grass, timothy has the lowest nitrate contents, and fluctuations in this level due to the use of fertilizer are the least (Baerug 1977 b).

In many cases the potassium content was much higher than 20 mg/g. This is considered to be a prerequisite for abundant growth in grasses harvested at the silage stage (Baerug 1977). The experiments thus exhibited luxurious consumption of potassium. A much lower potassium content is sufficient for dairy cattle (Anon. 1975) and one of the problems when using silage is, in fact, too high a potassium content in the forage compared with its magnesium content. In the present experiments the potassium content increased markedly as the amount of potassium fertilizer used increased. In the first crop the average increase was 0,7 mg/g and in the second 0,6 mg/g for each 10 kg of potassium in the fertilizer. Earlier experiments have shown the increase in the potassium content of grasses to be directly proportional to the amount of potassium fertilizer used on crops harvested as hay (Salonen and Tainio 1961).

The potassium content of the yield depended both on the potassium and nitrogen fertilizer and on the duration of the experiment (Fig. 2). The increase in potassium content which accompanied increases in the amount of nitrogen fertilizer was greatest in the first experimental year and was roughly the same for the different amounts of potassium used. In the second year the potassium content remained, on average, the same, irrespective of the amount of nitrogen fertilizer, and in the third year the potassium content fell considerably as more nitrogen fertilizer was used. The increase in the potassium content brought about by nitrogen fertilizer was also less marked in the third year, even for the highest amount of potassium used. This showed that the small amount of potassium was no longer sufficient to satisfy the potassium consumption brought about by large amounts of nitrogen fertilizer, even though the plants began to take large amounts of potassium from the soil (see p. 241). This indicates that the need for potassium fertilizer grows along with the age

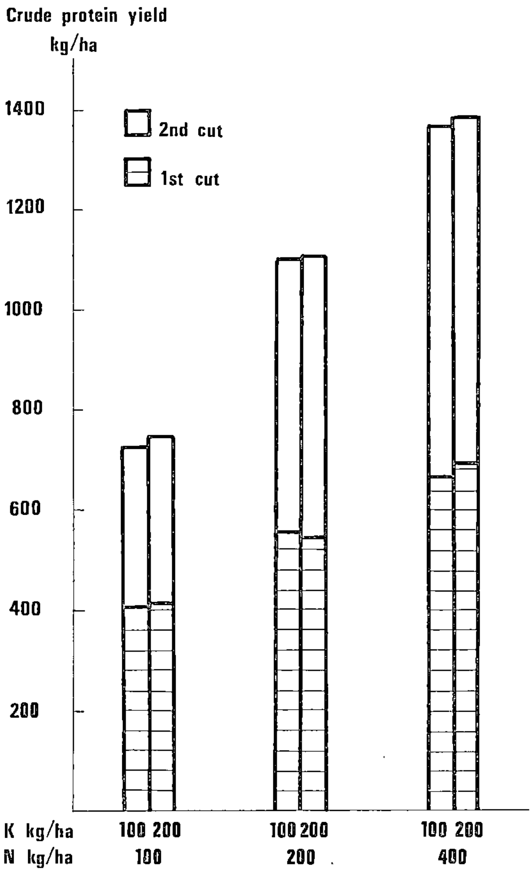

Fig. 2. Annual effect of nitrogen and potassium fertilizers on the crude protein yield (kg/ha) of silage grassland.

of the grassland. This was also found to be the case in some other studies (HÅLAND 1974, HERNES 1978).

If, in grassland cultivation, the aim is to avoid, on the one hand, impoverishment of the potassium in the soil and, on the other, undesirably high potassium level in the forage, the potassium fertilizer can be shared between the various cuts and greater emphasis can be given to applying the appropriate amounts of potassium on older grasslands. This is of particular relevance in northern Finland, where the soil often contains only small levels of potassium, and were sowing usually takes place ley after ley, in which case the large amounts of potassium fertilizer necessary cannot be applied to other plants of rotation. The use of large amounts of potassium when establishing grasslands has proved to be unfavourable (TÄHTINEN 1970).

The magnesium content of the crop of the first cut was lower than that of the second one and often below the level of 20 mg/g recommended for dairy cattle. However, use of nitrogen fertilizer produced a clear increase in the magnesium level in both crops since the ammonium nitrate limestone used in the experiments contained 2,7 % magnesium. Increasing the amount of potassium fertilizer lowered the magnesium content of timothy grass.

The use of fertilizer had a slight effect on the variation in calcium content at different experimental sites. Nitrogen fertilizer slightly increased the calsium content, whereas with potassium fertilizer the content fell slightly on average in the second cut.

A low feed magnesium content increases the risk of grass tetany in ruminants. Attempts have been made to estimate this risk using various cation equivalent ratios, e.g. K/(Ca+Mg). However, the threshold values for the risk vary slightly from one study to another. The K/ (Ca+Mg) ratio of the feed should be under 2,2 to avoid the risk of grass tetany (KEMP and T'HART 1957). In the material presented here, the ratio is above this in many of the experiments. The ratio was higher in the first crop than in the second. Increasing the amount of nitrogen

Table 4. Average nutrient contents of timothy grass, mg/g in dry matter, for the various treatments.

	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	Significances [1]			
							N_{1-2}	N_{1-4}	N_{2-4}	K_{1-2}
	1st cut (n = 32)									
N	22,0	21,9	26,1	25,4	31,1	32,1	**	**	**	
K	33,1	36,0	34,0	37,2	33,3	37,9				**
Mg ..	1,5	1,5	1,8	1,7	2,1	2,1	**	**	**	**
Ca ...	3,9	3,9	4,2	4,2	4,9	4,8	*	**	**	
P	3,6	3,7	3,8	3,8	3,9	4,0	*	**	*	
	2nd cut (n = 30)									
N	21,1	21,0	26,2	26,6	32,4	30,8	**	**	**	
K	31,2	33,1	32,0	35,5	31,9	35,2				**
Mg ..	1,8	1,7	2,2	1,9	2,6	2,3	**	**	**	**
Ca ...	4,9	4,7	5,2	4,9	5,7	5,2		**	**	**
P	3,3	3,3	3,5	3,5	3,6	3,5	**	**		

[1]) N × K-interaction is not significant.

fertilizer reduced the ratio due to the magnesium content of the fertilizer, whereas potassium fertilizer raised the K/ (Ca+Mg) ratio significantly. In individual experiments the difference was more often significant in the second than in the first crop (Mäntylahti 1975, cf. Rinne et al. 1978). On farms where grass tetany has been found to occur, animal feed should be supplemented with magnesium-containing mineral feeds, and the amount of potassium fertilizer used on grasslands, and how it is divided, should be studied. It is a good idea to use less potassium at the start of grassland cultivation than later on. If necessary, a sufficient supply of magnesium and calcium can be provided using dolomitic limestone when establishing leys.

There was relatively little change in the phosphorus content of the crop due to the experimental treatments used. In one or two experiments nitrogen fertilizer significantly increased the phosphorus content, particularly in the first cut. Increasing the amount of potassium fertilizer on the other hand, did not have any significant effect on the phosphorus content.

Red clover

In the few experiments where red clover was present in the stand the amounts of nitrogen and potassium fertilizer used had very little effect on the plant nutrient contents of the clover. Increasing the amount of nitrogen fertilizer produced a slight increase in the first cut and a drop in the potassium content, particularly when large amounts of nitrogen fertilizer were used (cf. Salonen and Hiivola 1963). The differences between the treatments were not significant.

Uptake of nutrients

Nitrogen fertilizer had a more pronounced effect on the uptake of nitrogen, i.e. on the total crude protein yield (Fig. 3), than on the dry matter yield since the nitrogen content increased greatly as the amount of nitrogen fertilizer increased, even with the largest amount of nitrogen.

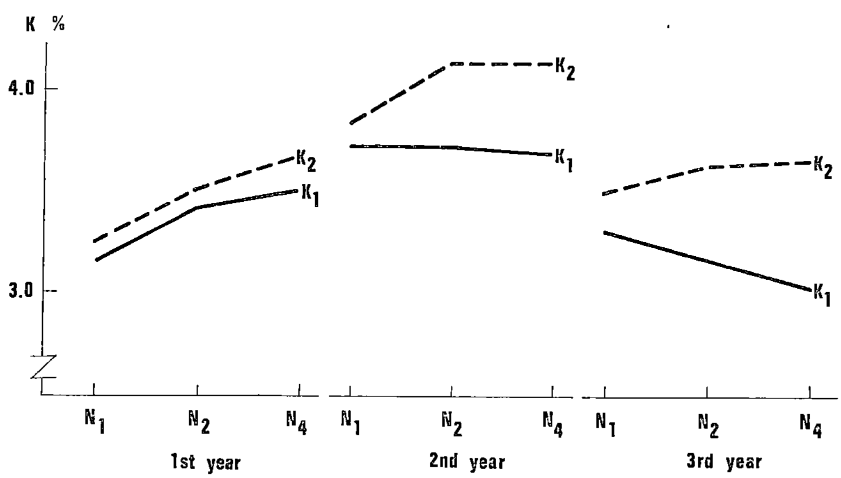

Fig. 3. Average effect of nitrogen and potassium fertilizers on potassium content of the dry matter from the first cut of timothy grass in various experimental years. Fertilizer per cut (kg/ha): $N_1 = 50$, $N_2 = 100$, $N_4 = 200$; $K_1 = 50$, $K_2 = 100$.

Table 5. Average nutrient contents of red clover, mg/g in dry matter, for the various treatments.

	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2
	1st cut (n = 7)					
N	26,9	27,8	28,0	27,2	30,5	32,5
K	34,1	36,3	34,7	34,8	28,6	26,6
Mg	3,1	3,3	3,0	3,3	3,3	3,2
Ca	11,1	11,6	11,3	11,4	10,7	11,2
P	2,8	2,9	2,7	2,8	3,0	2,9
	2nd cut (n = 4)					
N	27,7	27,5	27,6	28,3	30,0	27,9
K	31,5	32,5	31,3	34,0	30,4	31,2
Mg	3,4	3,6	3,7	3,6	3,7	3,4
Ca	11,4	12,1	11,2	11,6	10,1	10,2
P	2,3	2,4	2,4	2,4	2,4	2,3

The average crude protein yield obtained with 100 kg/ha of nitrogen increased c. 1,3 fold in the first cut compared with that obtained with 50 kg/ha, and with 200 kg of nitrogen the yield increased 1,7 fold. In the second cut the average increase in crude protein yield was almost double. The average relative values for the crude protein yields were 100 (N_1), 147 (N_2) and 184 (N_4). The average uptakes of nitrogen per kilogram of nitrogen in the fertilizer were 1,2, 0,9 and 0,5 kg per hectare. A decrease in the utilization of nitrogen as the amount of nitrogen fertilizer increases has also been shown in earlier studies (SALONEN et al. 1962, RAININKO 1968, RINNE et al. 1974).

Potassium fertilizer had no significant effect on the uptake of nitrogen. The potassium content of the soil had a less significant effect on the uptake of nitrogen than it did on the dry matter yield. The dependence of the effect of potassium on the soil potassium content was less noticeable in the crude protein yield than in the dry matter yield (r_{N1} = -0,09, r_{N2} = -0,64* and r_{N4} = -0,37, cf. p. 238).

The proportion of red clover in the ley stand generally has a marked effect on the uptake of nitrogen by the crop and thus also on the crude protein yield. In this study, the N_1K_1 plot in experiment 3 contained 32 % red clover in the first year. In this case red clover accounted for almost half of the crude protein yield. The proportion of red clover decreased considerably with increasing age of the ley and with increasing amounts of nitrogen fertilizer. The percentage increase in crude protein yield attained with the use of nitrogen fertilizer thus rose considerably in the following experimental years. Little crude protein was obtained with the small amount of nitrogen, especially in the third year of the experiment. The crude protein yields and ratios in experiment 3 are as follows:

	Crude protein yield kg/ha			Ratio		
	N_1	N_2	N_4	N_1	N_2	N_4
1st year	513	655	892	100	128	174
2nd year	920	1 413	1 967	100	154	214
3rd year	363	764	1 033	100	210	284

The same increasing trend due to nitrogen fertilizer over the years was observed in experiment 1, in which red clover accounted for 30 % of the stand, despite the incomplete data on yields in this experiment.

In the three-year experiments (experiments 4—8), in which the stands contained no red clover whatsoever, use of nitrogen fertilizer caused a yearly increase in the crude protein yield. The effect on the amount of crude protein obtained was greatest in the first year:

	Crude protein yield kg/ha			Ratio		
	N_1	N_2	N_4	N_1	N_2	N_4
1st year	692	1 079	1 413	100	156	204
2nd year	761	1 145	1 371	100	150	180
3rd year	851	1 271	1 537	100	149	181

According to EBBERSTEN (1974), the proportion of clover in mixed clover-grass stands tends to decrease, and this means that the effect of nitrogen on the crude protein yield becomes more noticeable along with the increasing age of the grassland and the number of harvests. This disappearance of clover from grasslands with a high clover content drastically reduces the crude protein yield.

The uptake of potassium varied considerably, particularly as the amount of nitrogen used

Table 6. Average uptake of nutrients, kg/ha/year, for the various experimental treatments.

	Treatments						Significances [1]			
	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	N_{1-2}	N_{1-4}	N_{2-4}	K_{1-2}
K-uptake	181,2	201,4	230,9	257,6	226,9	262,1	**	**		**
Mg-uptake	9,2	9,0	13,8	12,5	16,2	15,6	**	**	**	*
Ca-uptake	24,5	24,5	33,7	32,6	38,0	37,2	**	**	**	
P-uptake	19,2	19,8	25,1	25,5	26,3	26,8	**	**	*	

[1]) N × K-interaction is not significant.

varied (Table 6). While raising the amount of nitrogen from 50 to 100 kg/ha significantly increased the size of the crop it also resulted in an increase of 53 kg/ha in the average uptake of potassium during the growing season. The uptake of potassium did not increase from this figure when the highest amount of nitrogen was used. In several experiments with the small amount of nitrogen fertilizer was used, the uptake of potassium was greater than the amount of potassium supplied in the fertilizer, even for the smaller amount of potassium fertilizer. The tendency of potassium fertilizer to increase the potassium yield was significant in many of the experiments and was mainly due to the corresponding increase in the potassium content of experiments and was mainly due to the corresponding increase in the potassium content of the crop. The average uptake of potassium during the growing season increased by 30 kg/ha when the amount of potassium used was raised. When the smaller of the two amounts of potassium fertilizer was used the average potassium yield was twice as high as the amount of potassium supplied in the fertilizer.

Use of nitrogen fertilizer had a relatively marked effect on the uptake of magnesium. The average magnesium yields for the three amounts of nitrogen were 9,1, 13,1 and 15,8 kg/ha/year, respectively. The uptake of magnesium by the stand was smaller than the amount of magnesium contained in the nitrogen fertilizer. The effect of nitrogen fertilizer on the uptake of magnesium, especially in the first year, was greater the higher the soil magnesium content. Increasing the amount of potassium used reduced the uptake of magnesium, especially in the first crop.

Nitrogen fertilizer also increased the uptake of calcium (cf. RINNE et al. 1974), although in individual experiments the difference was seldom significant.

Nitrogen fertilizer also increased the uptake of phosphorus, both in terms of phosphorus yield and phosphorus content. The average uptakes of phosphorus from the soil by the first cut were 19,3, 25,2 and 26,3 kg/ha.

Effect of fertilizer on the soil

At the end of the experimental period the pH values and nutrient contents of the topsoil in six experiments were analysed for each of the experimental plots (Table 7). The experimental treatments had no significant effect on the soil acidity, with the exception of experiments 8 and 10, in which the pH fell as the amount of nitrogen fertilizer increased. Nitrogen fertilizer has also been shown to increase soil acidity in previous studies (SILLANPÄÄ and RINNE 1975).

The various treatments had their most marked effect on the ammonium acetate-extractable potassium content of the soil. The greatest significant effect was obtained with potassium fertilizer. Potassium fertilizer significantly increased the soil potassium content, even when this value was initially good. The average increase in potassium content was 55 mg/l. Nitrogen fertilizer generally lowered the soil potassium content. According to earlier studies this

Table 7. Effect of nitrogen and potassium fertilizers on the pH value and nutrient contents of the soil at the end of the experimental period (6 experiments).

Trial no.	N_1K_1	N_1K_2	N_2K_1	N_2K_2	N_4K_1	N_4K_2	Significances N	K	N×K
				pH					
1	7,4	7,4	7,4	7,4	7,3	7,3			
3	6,5	6,6	6,4	6,5	6,4	6,5			
5	5,1	5,2	4,9	5,1	4,9	4,9			
6	5,0	5,1	5,0	5,1	5,0	4,9			
8	5,6	5,6	5,5	5,4	5,1	5,1	**		
10	5,4	5,8	5,4	5,3	5,2	5,2	**		
				Ca mg/l					
1	4 825	4 650	4 675	4 625	4 700	4 265			
3	1 825	1 850	1 775	1 850	1 740	1 875			
5	1 300	1 290	1 250	1 225	1 165	1 165	*		
6	1 390	1 530	1 515	1 450	1 375	1 230	*		
8	1 375	1 390	1 400	1 390	1 200	1 025			
10	1 215	1 315	1 165	1 165	1 200	1 190			
				K mg/l					
1	243	310	268	265	263	339		*	
3	240	318	213	264	165	216	**	**	
5	108	155	98	143	95	153		**	
6	100	164	80	153	63	138		**	
8	95	143	100	133	113	148		**	
10	70	168	46	80	54	104	**	**	
				Mg mg/l					
1	88	84	89	77	92	81			
3	132	138	133	150	144	147			
5	242	228	215	197	172	172	**		
6	105	136	110	112	129	119			
8	141	140	156	150	141	119			
10	198	180	195	198	168	190			
				P mg/l					
1	90,2	92,0	96,0	86,5	90,7	101,2			
3	26,1	30,3	25,6	26,1	23,3	25,3			
5	16,5	15,6	19,8	18,4	19,2	16,8			
6	33,7	35,8	39,0	35,8	39,5	41,6			
8	31,0	26,3	25,4	27,2	29,5	26,0			
10	14,2	21,8	15,4	14,6	16,8	16,1			

reduction in the soil potassium content is smaller if the potassium fertilizer is divided between each crop than if it is applied in one lot in the spring (Lyngstad and Einevoll 1967, Peltomaa et al. 1979). In these present studies the soil potassium content remained unchanged when the smallest amounts of potassium and nitrogen were used (N:K = 1:1), irrespective of the fact that the amount of potassium given in the form of fertilizer was, on average, 65 kg less than that taken up from the soil by the crop in the growing season. When a larger amount of nitrogen was used the same amount of potassium slightly reduced the content of acid ammonium acetate-extractable potassium. In this study the smaller amount of potassium in relation to the nitrogen applied was sufficient to maintain the acid ammonium acetate-extractable potassium content of the soil when a larger amount of nitrogen fertilizer was used. With 100 kg/ha/cut of nitrogen the potassium content of the soil increased slightly when the N:K ratio was 1. With 200 kg/ha/cut of nitrogen the soil potassium content rose even with an N:K ratio of 2. The uptake of potassium and the acid ammonium acetate-extractable potassium content of the soil were highest in experiment 3, even though this experiment was carried out on a clay soil whose potassium content was satisfactory. According to Joy et al. (1973) grassland plant species take up the reserves of potassium from below the topsoil layer, in addition to the less soluble potassium from the soil. In this study, large amounts of nitrogen fertilizer frequently meant that the N:K ratio had to be small in order to maintain the soil potassium level.

Only in experiment 5 did the use of nitrogen fertilizer have a significant effect on the magnesium content of the soil. The magnesium level fell slightly as the amount of nitrogen fertilizer increased, despite the fact that the ammonium nitrate limestone added more magnesium to the soil than was taken up by the crop. The use of potassium fertilizer had no significant effect on the magnesium content.

The treatments had no effect on the soil phosphorus content.

Nitrogen had significant effects on the soil potassium level in experiment 5 (negative) and in experiment 6 (positive).

The combined effect of potassium and nitrogen fertilizer was not significant in any of the soil analysis results; in other words, the effect of these nutrients did not depend on the amount of the other nutrient used.

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SELOSTUS

Typpilannoituksen vaikutus säilörehunurmen kaliumin tarpeeseen

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Maatalouden tutkimuskeskus

Typpilannoituksen vaikutusta kaliumlannoituksen tarpeeseen heinäkasvinurmilla tai heinäkasvivaltaisilla säilörehunurmilla tutkittiin 2—3 vuotta jatkuneissa kenttäkokeissa. Nämä kaksitoista koetta sijoitettiin eri puolille Suomea 61 ja 66 leveyspiirin välille. Sato korjattiin kasvukautena kahteen kertaan. Molemmille sadoille annettiin typpeä 50, 100 tai 200 kg/ha ja kaliumia 50 tai 100 kg/ha. Fosforialuslannoitus annettiin vuosittain keväällä.

Typpilannoituksen lisääminen 50 kg:sta 100 kg:aan nosti kuiva-ainesatoa noin neljänneksellä. Suurin typpilannoitus ei enää lisännyt sadon määrää, mutta sadon typpipitoisuutta se kohotti niin voimakkaasti, että raakavalkuaissato lisääntyi vielä noin 25 %.

Runsas typpilannoitus alensi apila-heinäkasvinurmen apilapitoisuutta voimakkaasti. Pienimmälläkään typpimäärälläkään, 50 kg/ha, ei apila säilynyt kasvustossa. Kaliumlannoitusta lisäämällä ei voitu parantaa apilan säilymistä nurmissa.

Kaliumilla saatu satoero riippui merkitsevästi maan kaliumin pitoisuudesta vain käytettäessä 100 kg/ha/niitto tai enemmän typpilannoitusta. Tällöin vähän kaliumia sisältävillä mailla kaliumlannoituksen lisäys nosti satoa. Kaliumlannoituksen määrällä ei ollut merkitsevää vaikutusta raakavalkuaissadon suuruuteen.

Kaliumlannoituksen lisäys nosti sadon kaliumpitoisuutta. Samoin typpilannoitus, mikäli kasvien käytettävissä oli riittävästi kaliumia. Kaliumpitoisuuden nousua voitiin ehkäistä paitsi jaottamalla kalium eri niittokertojen sadoille myös painottamalla kaliumlannoitus voimakkaimpana vanhemmille nurmille.

Maan helppoliukoisen kaliumin pitoisuus säilyi suunnilleen ennallaan käytettäessä typpeä 50 kg/ha/niitto ja nosti hieman pitoisuutta typpitasolla 100 kg/ha/niitto, kun lannoituksessa suhde N:K=1. Voimakkaimmalla typpilannoituksella maan kaliumpitoisuus nousi vielä N:K=2.

ANNALES AGRICULTURAE FENNIAE VOL. 18: 246—251 (1979)

Seria AGRICULTURA N. 61 — Sarja PELTOVILJELY n:o 61

AMINO ACID COMPOSITION OF TIMOTHY, MEADOW FESCUE, COCKSFOOT AND PERENNIAL RYEGRASS AT TWO LEVELS OF NITROGEN FERTILIZATION AND AT SUCCESSIVE CUTTINGS

TIMO MELA and HERMANN RAND

MELA, T. & RAND, H. **Amino acid composition of timothy, meadow fescue, cocksfoot and perennial ryegrass at two levels of nitrogen fertilization and at successive cuttings.** Ann. Agric. Fenn. 18: 246—251. (Agric. Res. Centre, Inst. Plant Husb. SF-31600 Jokioinen, Finland.)

In experiments conducted in 1974 and 1975 the content of several amino acids in the spring growth of grass depended significantly on the stage of growth. As the grass aged, decreases occurred in aspartic acid, glutamic acid, alanine, tyrosine and phenylalanine, whereas increases were noted in threonine, serine and proline. The changes in the content of these amino acids during 10 days were 2,4—7,8 %. Amino acids that remained unchanged during the growth of the grass were lysine, histidine, arginine, glycine, valine, methionine, isoleucine and leucine. The total content of amino acids did not change significantly. An increase of the nitrogen fertilization from 50 to 100 kg/ha increased the aspartic acid content but did not affect the other amino acids. The amino acid composition did not differ significantly between timothy, meadow fescue, cocksfoot and perennial ryegrass.

Index words: Amino acid composition, protein quality, growth stage, date of cutting, nitrogen fertilization.

INTRODUCTION

During the last decade nitrogen fertilization of grass has increased, but doubts have been expressed about the quality of the additional protein obtained. It has often been suggested that nitrogen fertilization weakens the quality of the protein by changing its amino acid composition. As rather little information is available on this subject and on the influence of the growth stage of the grass on the quality of herbage, the present study was undertaken to widen the knowledge in this field.

MATERIAL AND METHODS

In 1974 and 1975 a field experiment was conducted at the Institute of Plant Husbandry, Agricultural Research Centre, Tikkurila (60°N), to study possible changes in quality with the date of cutting. Four successive cuts were taken during the spring harvest at the same stages of development in the two years. The first cut was taken when the tillers had 2—3 leaves, the second when they had 3—4 leaves, the third when the first panicles became visible, the fourth when all the panicles had emerged from the sheath. The dates of the cuttings were June 4, 11, 19 and July 3 in 1974, and May 22, June 2, 12 and 23 in 1975. There were two levels of nitrogen fertilization, 50 and 100 kg/ha.

Samples of herbage were chopped, dried at 60°C and ground. According to the studies of KALDY et al. (1979), amino acid analysis gave satisfactory results when samples of herbage were dried at 70°C. In the present study the amino acid analyses were made with automatic Hd 1200 E amino acid analyzer by the Estonian Research Institute of Agriculture and Land Improvement, Saku.

The statistical analysis of the results was performed by the Computing Service of the Agricultural Research Centre. The methods of regression and covariance analysis were mainly according to the principles of SNEDECOR and COCHRAN (1967). All the results were tested for their regression on the date of cutting. Comparison of the regression coefficients for the two years justified the assumption that the slopes of the regression lines did not differ, and that the results for the two years could be pooled. Yearly results did not differ significantly when they were compared at the same stage of growth. The equality of the slopes of the regression lines for the different levels of nitrogen fertilization and the different grass species on the corresponding dates of cutting was also tested before the results were combined.

The means were compared by Tukey's test.

RESULTS

Table 1. Average amino acid content (% in protein) of grass at different times of cutting.

Amino acid	2—3 leaves in tillers (n = 14)	2—3 leaves in tillers (n = 16)	First panicles visible (n = 16)	All panicles emerged (n = 16)
Lysine	5,43	5,49	5,40	5,37
Histidine	2,05	2,10	2,19	2,11
Arginine	4,98	4,71	4,66	4,90
Aspartic	8,60	7,84	7,73	7,63
Threonine	3,87	3,68	3,98	4,60
Serine	3,25	3,41	3,59	4,00
Glutamic	11,70	11,85	10,65	10,17
Proline	4,66	5,44	5,86	5,77
Glycine	4,29	4,28	4,34	4,20
Alanine	6,47	6,70	6,70	5,95
Valine	4,87	4,58	4,85	4,70
Methionine	1,39	1,51	1,53	1,24
Isoleucine	3,34	3,27	3,45	3,26
Leucine	6,56	6,55	6,49	6,51
Tyrosine	2,90	3,09	2,55	2,24
Phenylalanine	4,40	4,08	4,07	3,71
Total	78,76	78,58	77,86	76,36

Date of cutting

Table 1 shows the amino acid contents of the grass at different stages of growth. The values are the means of the results for both years, all four species and both levels of nitrogen fertilization.

The contents of a few amino acids may be seen to change during the development of the grass. The total content of the amino acids determined in the analysis also decreased from stage to stage. Regression analysis (Table 2) shows that the results of most of the amino acids analysed fit the regression line well. Curvilinear parabolic regression was not found to fit any better than linear regression.

According to the F-values of covariance analysis, the content of several amino acids depends significantly on the stage of growth. The contents of aspartic acid, glutamic acid, alanine, tyrosine and phenylalanine decreased with the age of the grass, whereas the contents of threonine, serine and proline increased. The changes in these amino acids during 10 days were 2,4—7,8 %. Between the first and the fourth cut, a period of 29 days in 1974 and 32 days in 1975, marked changes occurred in the contents. The date of cutting did not have a

Table 2. Analysis of regression of amino acid content in grass on day of cutting

Amino acid	Regression equation	Multiple correlation coefficient	Covariance analysis F-values
Lysine	y = 5,53—0,004 x	0,711***	0,98 (1,59)
Histidine	y = 2,08+0,001 x	0,485***	0,31 (1,59)
Arginine	y = 4,85—0,002 x	0,099	0,12 (1,59)
Aspartic	y = 8,71—0,034 x	0,402**	6,48* (1,59)
Threonine	y = 3,46+0,025 x	0,367*	8,30** (1,59)
Serine	y = 3,04+0,023 x	0,475***	17,14*** (1,59)
Glutamic	y = 12,35—0,057 x	0,390**	10,34** (1,59)
Proline	y = 4,65+0,035 x	0,416**	12,03*** (1,59)
Glycine	y = 4,33—0,002 x	0,161	0,47 (1,59)
Alanine	y = 6,86—0,017 x	0,393**	5,78* (1,59)
Valine	y = 4,73—0,0001 x	0,775***	0,00 (1,59)
Methionine	y = 1,28+0,007 x	0,435**	0,75 (1,59)
Isoleucine	y = 3,31—0,0003 x	0,725***	0,00 (1,59)
Leucine	y = 6,56—0,001 x	0,346*	0,10 (1,59)
Tyrosine	y = 3,20—0,025 x	0,661***	17,95*** (1,59)
Phenylalanine	y = 4,50—0,020 x	0,515***	11,63** (1,59)
Total amino acids	y = 79,68—0,082 x	0,320*	2,06 (1,59)

significant effect on the contents of lysine, histidine, arginine, glycine, valine, methionine, isoleucine or leucine. The change in the total content of the amino acids analyzed was not significant.

Nitrogen fertilization

According to regression and covariance analysis, with all but one of the amino acids, the contents did not differ significantly between the two levels of nitrogen fertilization (Table 3). The exception was aspartic acid. The regressions of the aspartic acid content on the date of cutting at nitrogen fertilization rates of 50 and 100 kg/ha are as follows:

Table 3. Content of amino acids in spring growth of grass at two levels of nitrogen fertilization (% in protein).

Amino acid	50 N (n = 32)	100 N (n = 30)	Average
Lysine	5,45	5,39	5,42
Histidine	2,13	2,09	2,11
Arginine	4,89	4,75	4,80
Aspartic	7,57 [1])	8,32 [1])	7,94
Threonine	4,15	3,91	4,03
Serine	3,65	3,50	3,57
Glutamic	11,05	11,10	11,07
Proline	5,48	5,44	5,46
Glycine	4,26	4,30	4,28
Alanine	6,45	6,46	6,45
Valine	4,69	4,81	4,75
Methionine	1,37	1,58	1,47
Isoleucine	3,35	3,31	3,33
Leucine	6,63	6,42	6,52
Tyrosine	2,73	2,54	2,63
Phenylalanine	4,10	4,01	4,05
Total amino acids	77,91	77,93	77,88

[1]) values differ significantly (P≤ 5 %) according to covariance analysis

N kg/ha	Regression equation	Multiple correlation coefficient	Covariance analysis (F-values) Date of cutting	N fertilization
50	y = 7,90—0,015x	0,242	0,91 (1,29)	7,66** (1,58)
100	y = 9,72—0,059x	0,605***	9,48** (1,27)	

The values in Table 3 are the means of the results for both years, all four species of grass and all four dates of cutting.

Grass species

When the regression of the different amino acids on the date of cutting were compared between the four grass species, covariance analysis did not reveal any significant differences, although the differences in the means can be fairly marked, for instance those of the proline content of timothy and perennial ryegrass (Table 4). The values in Table 4 are the means of the results for both years, all four dates of cutting and both levels of nitrogen fertilization.

Table 4. Content of amino acids (% in protein) in spring growth of four grass species. According to covariance analysis the species did not differ significantly in their amino acid content during their growth.

Amino acid	Timothy (n = 16)	Meadow fescue (n = 15)	Cocksfoot (n = 15)	Perennial ryegrass (n = 16)
Lysine	5,47	5,30	5,56	5,37
Histidine	2,06	2,06	2,20	2,14
Arginine	4,71	4,73	5,03	4,76
Aspartic	8,12	7,72	8,01	7,86
Threonine	3,93	3,87	4,33	4,02
Serine	3,50	3,52	3,65	3,63
Glutamic	10,30	11,23	11,19	11,59
Proline	5,05	5,43	5,30	6,05
Glycine	4,21	4,21	4,43	4,26
Alanine	6,60	6,39	6,56	6,26
Valine	4,59	4,55	5,00	4,85
Methionine	1,31	1,37	1,89	1,34
Isoleucine	3,24	3,31	3,40	3,37
Leucine	6,29	6,40	6,73	6,70
Tyrosine	2,67	2,49	2,75	2,65
Phenylalanine	3,96	4,08	4,21	3,99
Total	76,08	76,70	79,91	78,90

DISCUSSION

The amino acid composition of grass observed in the present study corresponds to the patterns mentioned in the literature (Wilson and Tilley 1965, Goswami and Wilcox 1969, Chibnall et al. 1965, Treviño and Hernandez 1977, Kaldy et al. 1979). Nevertheless, the differences between the present results and those of other workers are greater than those between the different grass species in the present study. In his review Lyttleton (1973) also remarked that there is considerably more differences between the analyses produced by different laboratories for one plant than between different plants analyzed in the same laboratory. One reason is differences in the analytical methods; another possible reason, suggested by the present results, is differences in the growth stage of the grass at the time of sampling.

The amino acid composition reported for alfalfa (Treviño and Hernandez 1977, Kaldy et al. 1979) is surprisingly similar to that of the grasses in the present study. The greatest difference is that in the content of aspartic acid, which is several percentage units higher in alfalfa than in grass herbage.

The results of the present study indicate that suspicions about the unfavourable influence of nitrogen fertilization on the amino acid composition of grass have been groundless. A twofold increase in nitrogen fertilization failed to change the amino acid composition of the grass. Goswami and Willcox (1969) have come to the same conclusion.

Previous results concerning the effect of the date of cutting on the amino acid composition of grass vary somewhat. According to Waite et al. (1953) and Hodgson (1964), the amino acid composition of the protein does not alter as the grass ages. Treviño and Hernandez (1977) report a slight decrease in the amino acid content of grass during development. According to the statistical analysis of the results of the present study significant decreases and increases occur in the contents of some amino acids.

It may be noted that both the protein and amino acid contents of the dry matter of grass depend strongly on nitrogen fertilization, as is evident from the following results of regression analysis:

N kg/ha	Average of results	Regression equation	Covariance analysis (F-values) Date of cutting	N fertilization
In dry matter				
50 ...	10,78	y = 17,33—0,297x	230,53*** (1,29)	46,13*** (1,58)
100 ...	12,90	y = 21,60—0,377x	261,46*** (1,27)	

If the amino acid yields were calculated, they would be found to change in the same manner as the protein yields.

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SELOSTUS

Typpilannoituksen ja niittoajan vaikutus timotein, nurminadan, koiranheinän ja monivuotisen raiheinän valkuaisen aminohappokoostumukseen

TIMO MELA ja HERMANN RAND

Maatalouden tutkimuskeskus ja Eestin Maanviljelyksen ja Maanparannuksen tutkimuslaitos

Maatalouden tutkimuskeskuksen kasvinviljelylaitoksen koekentillä vuosina 1974 ja 1975 suoritetuista säilörehunurmen korjuuaikakokeista määritettiin Eestin Maanviljelyksen ja Maanparannuksen Tutkimuslaitoksessa Sakussa 16 aminohapon pitoisuus. Näytteet edustivat timotein, nurminadan, koiranheinän ja monivuotisen raiheinän kevätsadon neljää eri kehitysastetta: 1) versoissa 2—3 lehteä, 2) versoissa 3—4 lehteä, 3) ensimmäiset tähkät ja röyhyt puhkeamassa tupesta, 4) kaikki tähkät ja röyhyt täysin puhjenneet tupesta. Typpilannoitustasoja oli kaksi, 50 ja 100 kg/ha. Maatalouden tutkimuskeskuksen laskentatoimistossa suoritettiin määritystulosten tilastollinen analyysi. Tulosten mukaan useiden aminohappojen pitoisuus riippui tilastollisesti merkitsevästi ruohon kehitysasteesta. Ruohon vanhetessa asparagiinihapon, glutamiinihapon, alaniinin, tyrosiinin ja fenyylialaniinin pitoisuus valkuaisessa pieneni, treoniinin, seriinin ja proliinin pitoisuus taas suureni. 10 päivän aikana näiden aminohappojen pitoisuus muuttui 2,4—7,8 %. Valkuaisen lysiinin, histidiinin, arginiinin, glysiinin, valiinin, metioniinin, isoleusiinin ja leusiinin pitoisuus pysyi muuttumattomana ruohon vanhetessa, samoin myös valkuaisen aminohappojen kokonaispitoisuus.

Heinälajit eivät poikenneet aminohappokoostumukseltaan toisistaan. Typpilannoituksen lisäys 50 kg:sta 100 kg:aan hehtaarille suurensi vain asparagiinihapon pitoisuutta, mutta ei vaikuttanut muiden aminohappojen pitoisuuteen. Runsas typpilannoitus ei siis näyttänyt aiheuttavan epäedullisia muutoksia ruohon aminohappokoostumuksessa, kuten usein on epäilty tapahtuvan.

Tuloksia tarkasteltaessa on huomattava, että vaikka typpilannoituksen lisäys ei juuri vaikuta ruohon valkuaisen aminohappokoostumukseen, ruohon kuiva-aineen valkuaisen ja aminohappojen pitoisuutta ja määrää se lisää voimakkaasti.

ANNALES AGRICULTURAE FENNIAE VOL. 18: 252—262 (1979)

Seria ANIMALIA DOMESTICA N. 50 — Sarja KOTIELÄIMET n:o 50

MINERAL CONTENT IN HEAVILY NITROGEN FERTILIZED GRASS AND ITS SILAGE

Elsi Ettala and Vappu Kossila

Ettala, E & Kossila, V. 1979. **Mineral content in heavily nitrogen fertilized grass and its silage.** Ann. Agric. Fenn. 18: 252—262. (Agric. Res. Centre, North Savo Exp. Sta., SF-71750 Maaninka, Finland.)

Silage was prepared for feeding experiments with heavily N fertilized grass at five experimental stations in different parts of Finland in 1971—1972 (82 % of the meadows received 60—100 kg N/ha/harvest). The average crude protein content of the grass dry matter was 19,5 %, and that of silage 19,8 %.

The silage DM contained an average of 0,27 % calcium, 0,32 % phosphorus (the Ca/P ratio was 0,8), 0,21 % magnesium, 2,50 % potassium, and 0,04 % sodium. The grass DM contained 0,31 %, 0,39 %, 0,25 %, 3,26 %, and 0,06 %, respectively. The mean K/(Ca+Mg) ratio (equiv. basis) in grasses was 2,49 and in silages 2,24 respectively; in spring harvests the K/(Ca+Mg) ratio was 3,24 and 2,78, respectively.

The silage DM contained an average of 0,06 % iron, 97,9 ppm manganese, 34,2 ppm zinc, 11,2 ppm copper, 0,43 ppm molybdenum, 0,015 ppm selenium, and 0,26 ppm cobalt. The iodine content varied from less than 1 mg to 4 mg/kg DM. Zinc and selenium contents of all samples were below the nutritional standards recommended for livestock. Copper content was below the standards in the northern areas. The iodine content was sufficiently high only at North Pohjanmaa experimental station. Trace element contents of grass DM were: 0,05 % Fe, 113,6 ppm Mn, 45,1 ppm Zn, 11,2 ppm Cu, 0,38 ppm Mo, 0,014 ppm Se, and 0,22 ppm Co.

Illnesses caused by deficiency or imbalance of minerals in fodder did not occur in the experimental animals. Deficiencies were avoided by using mineral mixtures.

Index words: Mineral content, grass, silage.

INTRODUCTION

Nitrogen fertilization on meadows affects the uptake of many plant nutrients. Heavy N fertilization has a strong effect on the upptake of potassium; the potassium content of grass increases if the potassium content of soil is high, and decreases where it is low (Kemp 1960, Rinne et al. 1974 a, Tähtinen 1979). At low potassium levels, the N fertilization increased calcium, magnesium and sodium contents of grass, whereas at high potassium levels these contents decreased (Kemp 1960, Reith et al. 1964, Rinne et al. 1974 a and b, Hernes 1978). The N fertilization increased zinc and copper contents of grass, but decreased iron, manganese and molybdenum contents (RINNE et al. 1974 b); the effect on the phosphorus and cobalt contents was minor and varied (REITH et al. 1964, RINNE et al. 1974 a and b).

In cattle, high potassium content as well as low magnesium, calcium and sodium contents of grass increase the risk of hypomagnesaemia (KEMP and HART 1957, KEMP 1960, METSON et al. 1966). A high grass potassium content is negatively related to its Mg content and also depresses magnesium absorption from the gut into the blood of the animals (FONTENOT et al. 1973, TOMAS and POTTER 1976). The risk of hypomagnesaemia is further increased by high nitrogen content in grass (KEMP 1960, METSON et al. 1966).

During the last few years in Finland, relatively heavy nitrogen fertilization has been applied on meadows from which silage has been prepared for cattle. In this way it has been possible to reach a high degree of protein self-sufficiency in ruminant nutrition. Since the proportion of silage in the diet of cows can be very high, it is important to know how much mineral they can get from the silage, and how nitrogen fertilization affects the mineral contents of silage. It is also important to know the differences in the mineral contents between grass and the silage prepared from it. Feeding experiments on silage prepared from grasses heavily fertilized with nitrogen were started in 1969. Results concerning the mineral contents of grasses and silages of the first two years (1969 and 1970) have been reported earlier (KOSSILA et al. 1973, 1974). The present study is a continuation of these.

MATERIAL AND METHODS

Experimental silages were prepared at five experimental sites in different parts of Finland: on the experimental farm of the Agricultural Research Centre in Tikkurila, Vantaa, on the Häme Experimental Station in Pälkäne, on the North Savo Experimental Station in Maaninka, on the North Pohjanmaa Experimental Station in Ruukki and on the Lapland Experimental Station, Apukka near Rovaniemi.

The majority (84 %) of the meadows contained mixed grasses with timothy as the dominant species. About 10 % were mainly cocksfoot and about 6 % Italian ryegrass. Most of the herbage (45 %) received 100 kg N/ha/harvest; 37 % received 60—80 kg N and 18 % 33 kg N/ha/harvest. 43 % of the silage was made from spring harvest, 28 % from midsummer and 29 % from autumn harvest.

The grass was harvested as fresh with a flail-type forage harvester and mainly stored in tower silos, and also in clamps at the North Pohjanmaa Experimental Station (ETTALA and KOSSILA 1980). Preservative (4—5 litres for each ton of grass) was applied with an additive applicator during chopping.

21 % of the fodder was preserved with formic acid, 35 % with AIV 2-solution (83 % formic acid + 2 % orthophosphoric acid), 17 % with AIV 1-solution (20 % formic acid + 20 % hydrochloric acid), and 25 % with VIHER-solution (20 % formaldehyde + 24 % acetic acid).

In order to obtain corresponding samples of grass and silage a sample was taken for analysis from each load of mixed grass and the grass was packed into two jute sacks (15 kg each) for ensilage. The sacks were stored together with the rest of grass load in the same layers of fodder in the silo. In tower silos the distance between the sacks was about 1—2 metres. The silage samples were obtained in winter when the sacks came up during the course of feeding. To calculate the ensilage losses, the contents of each sack were weighed (ETTALA and KOSSILA 1980).

Feed analyses and mineral determinations were made on the grass sample and the two corresponding silage samples.

Feed analysis was carried out according to standard methods. The contents of calcium, magnesium, potassium, sodium, iron, manganese, zinc, and copper were determined with an atomic absorption spectrophotometer Type 603 (Perkin-Elmer Co. country of manufacture) according to the instructions »Standard Conditions». 5 g of the sample was burned at 480°C for 48 hours. Ash was dissolved into $HClO_4HCl$ mixture. The solution was diluted to 50 ml. Phosphorus was determined spectrophotometrically as a vanadium-molybdenum complex (ANON 1975). The cobalt content was determined with a graphite furnace method by using the atomic absorption spectrophotometer Perkin-Elmer Type 300. The feed samples were pretreated as follows: 5 g of the sample was pyrolysed with an HNO_3 $HClO_4$ solution, whereafter APDC-DDTC complex (ammonium pyrrolidine dithiocarbamate-diethylammonium-diethyldithiocarbamate) was formed at pH 3,5, and finally extracted with MIBK (methylisobutylketone). Molybdenum was determined spectrophotometrically as a toluol-3,4-dithiol complex (SCHOLL 1963). Selenium was determined as a 2,3-diaminonaphthalene complex spectrofluorometrically (PARKER and HARVEY 1962, FARLEY and WINKLER 1963). Iodine was determined using an ion-selective eloectrode analysis (HOOVER et al. 1971). Cobalt, molybdenum, selenium, and iodine were determined from only a small number of the samples.

RESULTS AND DISCUSSION

Feeds

Average dry matter content (DM) of the grass was 18,5 ± 3,6 % and that of the corresponding silage 21,5 ± 2,9 % (Table 1). Grass DM contained 9,3 ± 2,5 % and silage DM 8,1 ± 2,6 % of ash. Crude protein content of DM of grasses was 19,5 ± 3,0 % and that of silages 19,8 ± 2,8 %. Crude fibre contents were 23,7 ± 3,4 % and 27,4 ± 3,6 %, respectively.

Table 1. Chemical composition of grass and its silage.

Component	Grass (N = 153) $\bar{x}$ ± SD		Silage (N = 306) $\bar{x}$ ± SD	
Dry matter	18,5	3,6	21,5	2,9
In dry matter, %:				
Ash	9,3	2,5	8,1	2,6
Crude protein	19,5	3,0	19,8	2,8
Crude fat	3,8	0,6	6,1	1,1
Crude fibre	23,7	3,4	27,4	3,6
Nitrogen free extract	43,7	3,6	38,6	3,4

N = number of cases, $\bar{x}$ = mean, SD = standard deviation

Macrominerals

Calcium (Ca): Grass DM contained little more Ca, 0,31 ± 0,17 %, than silage DM, 0,27 ± 0,13 % (Table 2).

The Ca content of grass and silage was significantly influenced by location, year and number of mowings (Table 2). Ca content was highest in Vantaa and lowest in the North Pohjanmaa Experimental Station. In the autumn (September) harvest the calcium content was considerably higher than in the spring (June) or midsummer (August) harvests. In the previous experiments in 1970 the Ca content of silage was also highest in Vantaa and higher in the autumn than in the other harvests (KOSSILA et al. 1973, 1974).

Results indicate that from 1970 to 1972 the Ca content of grass and silage has decreased with time. In 1970 silage was prepared on the same experimental sites as in 1971 and 1972. In 1970 the average Ca content of grass DM was

Table 2. Mineral content of grass and its silage.

	No of samples		% in dry matter									
			Ca		P		Mg		K		Na	
	Grass	Silage	Grass	Silage	Grass	Silage	Grass	Silage	Grass	Silage	Grass	Silage
Experimental stations												
Vantaa	27	54	0,54	0,39	0,36	0,29	0,26	0,22	4,28	2,88	0,06	0,03
Häme	17	34	0,29	0,29	0,41	0,34	0,24	0,20	3,52	2,90	0,05	0,05
North Savo ..	49	98	0,28	0,24	0,36	0,28	0,21	0,17	3,61	2,54	0,05	0,03
North Pohjanmaa	39	78	0,23	0,23	0,40	0,37	0,24	0,22	2,57	2,27	0,06	0,05
Lapland	19	38	0,26	0,24	0,44	0,36	0,39	0,31	2,14	1,99	0,07	0,05
Years												
1971	81	162	0,36	0,31	0,36	0,31	0,27	0,23	3,16	2,48	0,05	0,04
1972	70	140	0,26	0,23	0,42	0,34	0,23	0,20	3,39	2,53	0,06	0,04
Mowings												
1st	65	130	0,27	0,21	0,39	0,31	0,20	0,17	3,51	2,46	0,05	0,04
2nd	42	84	0,27	0,25	0,38	0,33	0,30	0,25	2,70	2,21	0,06	0,05
3rd	44	88	0,42	0,37	0,38	0,35	0,28	0,25	3,44	2,85	0,05	0,04
Mean			0,31	0,27	0,39	0,32	0,25	0,21	3,26	2,50	0,06	0,04
SD			±0,17	±0,13	±0,08	±0,07	±0,09	±0,08	±0,95	±0,60	±0,04	±0,02
F-values of the differences												
Experimental stations			52,2***	47,4***	5,4***	30,0***	51,6***	66,4***	40,4***	16,4***	1,1	9,9***
Years			9,4**	24,3***	25,4***	27,9***	3,2	9,8**	9,3**	3,5	2,1	0,2
Mowings			48,7***	114,3***	1,2	10,6***	61,5***	119,9***	0,4	12,8***	1,0	1,9

*) $P < 0,05$, **) $P < 0,01$, ***) $P < 0,001$. Statistical method was a 3-factor variance analysis.

0,47 % (Kossila et al. 1973), in 1971 0,36 %, and in 1972 0,26 % (Table 2). The Ca content of silage DM was 0,43 %, 0,31 % and 0,23 %, respectively. Experimental silages were probably not prepared from grass grown on exactly the same fields in each year. Nevertheless, all meadows in question were heavily fertilized with nitrogen. When comparing the results of the present study with those obtained earlier one must bear in mind that the methods of analysis applied by Kossila et al. (1973) differed to some extent from those applied in 1971 and 1972.

Phosphorus (P): Grass DM contained an average of 0,39 ± 0,08 % and silage DM 0,32 ± 0,07 % of phosphorus (Table 2).

The differences in P contents between experimental sites were significant, but less prominent than the differences in Ca contents (Table 2). Contrary to the Ca contents, the P contents were highest at the experimental station in the north. No such trend was observed in the experimental silage of 1970 (Kossila et al. 1973), but it was observed in samples of timothy collected from different plant cultivation zones (Kähäri and Nissinen 1978).

Between harvests the differences in P contents were negligible in grass, but grew during ensilage due to variations in the volume of the P losses (Ettala and Kossila 1980).

The P content of grass increased with time. On the experimental sites in 1970 the average P content in grass DM was 0,32 % (Kossila et al. 1973), in 1971 0,36 % and in 1972 0,42 %. Silages contained 0,26 %, 0,31 % and 0,34 % P, respectively. A similar trend can be seen in a survey by Rinne et al. (1974 a) as well as in a study on timothy by Kähäri and Paasikallio

(1977). The rise in P contents is evidently due to an increase in P fertilization.

Magnesium (*Mg*): Grass DM contained an average of 0,25 ± 0,09 % and silage 0,21 ± 0,08 % Mg (Table 2).

Differences in Mg contents between experimental sites were significant. The highest Mg content was obtained at the northernmost station i.e. the Lapland Experimental Station, the lowest at the North Savo Experimental Station. The Mg content of the spring harvest was lower than that of the midsummer and autumn harvest. In the previous years the results obtained were similar as to both the experimental site and harvest (Kossila et al. 1973, 1974).

At the same sites the average Mg content in the grass DM was 0,23 % in 1970 (Kossila et al. 1973), 0,27 % in 1971, and 0,23 % in 1972. Therefore no consistent trend was observable during these years. The respective Mg contents in silage were 0,18 %, 0,23 % and 0,20 %.

Potassium (K): Grass DM contained 3,26 ± 0,95 % and silage DM 2,50 ± 0,60 % K (Table 2).

The K content of grass dropped clearly when proceeding from south to north (Table 2). At the Lapland Experimental Station the average K content of grass was about one half (2,14 % of DM) of the K content obtained in Vantaa (4,28 % of DM). Due to the great loss in potassium during ensilage, the K content of silage was considerably lower than that of the grass (Ettala and Kossila 1980). Differences in K contents between sites were smaller in silage than in grass. Similar results have been obtained in earlier years (Kossila et al. 1973).

The K content was lowest in the midsummer harvest, but in comparison to the other harvests, this was not significant. However, the K contents of silages varied significantly between mowings due to differences in losses (Ettala and Kossila 1980). In the experiments of Rinne et al. (1974 a), the K content of the first harvests of the summer was markedly higher than that of the other harvests.

The K content of grass rose slightly from 1970 to 1972. In 1970 the average K content of grass DM was 3,09 % (Kossila et al. 1973), in 1971 3,16 %, and in 1972 3,39 %. The respective contents of silage DM were 2,30 %, 2,48 % and 2,53 %. On clay and silt soils Rinne et al. (1974 a) observed an increase in K content of grass. However, on coarse mineral soils as well as on organic soils the K content of the yields dropped with the diminishing potash resources of the soils (Rinne et al. 1974 a, Sillanpää and Rinne 1975).

Sodium (Na): Grass DM contained an average of 0,06 ± 0,04 % and silage DM 0,04 ± 0,02 % Na (Table 2).

In grass, no large differences in Na contents were noticed between experimental sites, years or mowings (Table 2). On the other hand, the Na contents of silages differed significantly from one another at different experimental sites, because there was considerable variation in Na losses (Ettala and Kossila 1980).

Macromineral contents and livestock nutrition

A Ca/P ratio of 1 to 2 is regarded as optimal for livestock (Jacobson et al. 1972, NJF 1975). The average Ca/P ratio of silage in this study was only 0,8. The value has decreased below the optimum quite rapidly. In 1970, the mean Ca/P ratio of the experimental silage was 1,7 in 1971 1,0, and in 1972 0,7.

In the study by Rinne et al. (1977) the Ca/P ratio of heavily N fertilized grass increased with time. In their study the largest amounts of nitrogen applied were twice the amounts of the present study, which may explain the difference between the results of these two studies. In the study of Rinne et al. the difference in fertilization also led to a decrease in the exhangeable potassium content in soil, to a decrease in the K content of grass as well as to an increase in the Ca content of the grass. In fact, in their study, the Ca content of grass was lowest when the level of N fertilization corresponded to that of the present study (60—100 kg/ha/harvest), the latter being a normal level in practical farming.

The Ca/P ratio of silage should be higher since increasing milk yield requires higher amounts of P rich concentrates in the diet of cows. Also in hay, the Ca/P ratio has decreased below 1,0; the ratio in timothy hay was 0,9 in the recent study of KÄHÄRI and NISSINEN (1978). The Ca content of grass could be increased through liming and rationing the potassium input into several applications according to the minimum requirements of the plant (JOKINEN 1977, PELTOMAA et al. 1979).

The K/(Ca+Mg) ratio (equiv. basis) of grass is an indicator of the risk of hypomagnesaemia (KEMP and HART 1957). If the ratio exceeds 2,2, a risk of hypomagnesaemia exists. In the study of RINNE et al. (1978) the heavy N fertilization first increased this ratio, and later decreased it together with the lowering of potash resources of the soil. In the present study the K/(Ca+Mg) ratio, calculated by using mean contents, was 2,49 in grass and 2,24 in silage. The mean ratio was highest in spring grass 3,24, and silage 2,78, respectively. For livestock the best ratio was obtained in the midsummer yields: 1,92 in grass, 1,83 in silage on average. The best ratio, an average of 1,44, was obtained for silage prepared at the Lapland Experimental Station.

No cases of hypomagnesaemia occurred in the test animals during the years 1970—72.

Deficits in the intake of various minerals were avoided by giving mineral mixtures to the animals. These mixtures contained among others, magnesium and sodium in large quantities. For the animals the only advantage was that during the ensilage process, the losses of potassium were larger than the losses of other minerals; and particularly large K losses (about 40 %), occurred in silage with high K content (ETTALA and KOSSILA 1980). Severe bone disorders and tetany, characterized by decreased serum Ca, Mg and P values and elevated alkaline phosphatase values have recently been reported in growing dairy cattle fed large quantities of grass silage without addition of mineral mixture into the diet (KOSSILA et al. 1977).

In later feeding trials, in which silages made from wilted grass were studied, symptoms of hypomagnesaemia were observed in cows. for the first time. In such silages potassium is not discharged with effluent and therefore potassium content is higher compared to that in unwilted ones (ETTALA and KREULA 1979) According to PULSS and HAGEMEISTER (1971), absorption of magnesium from gut into blood was lower in animals fed wilted than in those fed unwilted silage.

A potassium content of 0,5—0,8 % in the DM is sufficient for animals (NJF 1975). A maximum yield from grass is obtained when the K content is a minimum of 1,6 % of the DM (REITH et al. 1964). When the K content in grass DM was 2—3 %, no problems arising from potassium content appeared. The contents exceeding 3 % in DM have been questionable (KEMP 1960, JACOBSON et al. 1972).

The Mg requirement of animals is satisfied if the diet DM contains at least 0,2 % Mg (KEMP 1960). The Mg content in silages remained below this standard in the spring harvest and in the feed at the North Savo Experimental Station (Table 2). The deficit was compensated for by using mineral mixtures containing 5 % magnesium. The Mg content of herbages can be increased with Mg fertilizers (JOKINEN 1977 b, JAAKKOLA and VOGT 1978), dolomite liming and evenly distributed fertilization with potash (PELTOMAA et al. 1979).

Compared to the recommended requirements for animals, there was far too little sodium in the feeds. According to SAALBACH and AIGNER (1970) it is very complicated to increase the Na content of timothy to the level required by cattle (0,15 % in DM). The lack of sodium is eliminated simply by giving mineral mixtures with high Na content to the animals.

Trace elements

Iron (Fe): Grass DM contained 0,05 ± 0,04 % and silage DM 0,06 ± 0,05 % iron (Table 3). In view of the Fe requirement of the animals being about 100 mg/kg DM (NJF 1975), the Fe content is fairly high. However, the Fe content may partly be caused by soil contamination in connection with mowing.

The Fe contents of grass varied significantly between sites, but not between years and mowings. Silage DM contained more Fe compared to raw material. This is apparently due to the fact that Fe occurrs mainly in relatively insoluble forms which remain in silage while some other more soluble grass constituents pass readily into effluent (Ettala and Kossila 1980). In the 1970 experiments the Fe content of silage was also higher than the Fe content of raw material (Kossila et al. 1973). Part of the Fe as well as the Na in grass and silage come from various contamination sources (soil, equipment, analytical problems etc.).

Manganese (Mn): Mn content was 113,6 ± 37,2 mg/kg DM of grasses and 97,9 ± 34,0 mg/kg DM of silages (Table 3). At all the experimental stations the Mn contents of silages were adequate according to the standards, 40—80 mg/kg DM (NJF 1975). The lowest contents were obtained in Vantaa and at the North Savo Experimental Station. Similar results were obtained in 1970 (Kossila et al. 1973). Years had no effect on the Mn content of grass and silage. The spring harvests contained much less manga-

Table 3. The Fe, Mn, Zn and Cu contents in grass and its silage (on dry matter basis).

	No of samples		Fe, %		Mn, ppm		Zn, ppm [1]		Cu, ppm	
	Grass	Silage	Grass	Silage	Grass	Silage	Grass	Silage	Grass	Silage
Experimental stations										
Vantaa	27	54	0,07	0,09	94,4	73,4	55,8	45,7	13,9	14,4
Häme	17	34	0,07	0,05	149,9	114,9	75,1	34,1	12,8	14,8
North Savo ..	46	98	0,04	0,05	86,6	77,7	33,3	29,9	12,0	11,6
North Pohjanmaa	39	78	0,04	0,05	138,7	126,0	38,6	32,5	9,7	9,2
Lapland	19	38	0,06	0,08	126,3	112,1	59,0	32,4	6,6	6,5
Years										
1971	81	162	0,05	0,07	113,9	98,1	46,4	35,7	11,0	11,2
1972	67	140	0,05	0,05	113,2	97,7	43,6	32,4	11,4	11,2
Mowings										
1st	65	130	0,06	0,08	97,1	81,7	42,9	34,0	10,0	10,9
2nd	42	84	0,04	0,06	127,2	111,1	41,7	31,0	9,9	9,1
3rd	44	88	0,05	0,05	124,9	109,3	52,5	38,1	14,0	13,5
Mean			0,05	0,06	113,6	97,9	45,1	34,2	11,2	11,2
SD			±0,04	+0,05	±37,2	±34,0	±17,9	±8,8	±6,9	±3,6
F-values of the differences										
Experimental stations			4,2**	8,7***	22,8***	42,7***	15,8***	55,5***	4,5**	64,6***
Years			0,8	17,0***	0,2	0,1	0,0	6,8**	1,4	1,4
Mowings			1,5	7,0***	4,3*	11,9***	0,0	14,5***	5,9**	12,0***

*) P < 0,05, **) P < 0,01, ***) P < 0,001. Statistical treatment, see Table 1.

[1]) Some exceptionally high Zn contents were disregarded because the samples were suspected to have been contaminated

nese than the summer and autumn harvests. This was also observed in the 1970 study (Kossila et al. 1974).

The content of *zinc* (Zn) in grass was 45,1 ± 17,9 mg/kg DM, and in silage 34,2 ± 8,8 mg/kg DM (Table 3). The Zn content of grass and especially that of silage was inadequate for cattle according to the standards, 50 mg/kg DM (NJF 1975). Similar results were obtained in silage in 1969—1970 (Kossila et al. 1973). The deficits have been replaced by zinc additives in mineral mixtures given to the animals.

The lowest Zn content was obtained at the North Savo Experimental Station (Table 3). The Zn content of grass did not vary significantly between years or mowings. It did, however vary due to variation in the quantity of Zn losses (Ettala and Kossila 1980). The Zn contents of silages obtained in this study were at about the same level as the Zn contents of timothy harvested from different parts of the country (Kähäri and Nissinen 1978). The Zn content of grasses could be increased by using fertilizers containing zinc (Jaakkola and Vogt 1978).

The *copper* (Cu) content of grass was 11,2 ± 6,9 mg/kg DM and in silage 11,2 ± 3,6 mg/kg DM (Table 3). The mean Cu content was adequate according to the standard, 10 mg/kg DM (NJF 1975). However, in the northern parts of the country Cu content stayed below the standard. Similar results were obtained for silage in 1970 (Kossila et al. 1973).

The average Cu contents of grass and silage were the same. On some experimental sites the content rose, on others it fell slightly during ensilage. No differences were observed between years. The Cu content of the autumn harvest was higher than that of the spring and summer harvests.

The average *molybdenum* (Mo) content of grass was 0,38 mg/kg DM, and of silage 0,43 mg/kg DM (Table 4). According to recommended standards, (NJF 1975) the Mo content of the diet should be 0,1—0,5 mg/kg DM. The Mo contents obtained in this experiment were adequate. The Mo contents varied considerably; the lowest values were obtained in Vantaa. The autumn harvest was more Mo rich than the other harvests In 1972 the Mo content of silage was twice that obtained in 1971. It has also been observed that the Mo content of timothy samples collected from different parts of the country vary considerably, but the average content is about the same as the contents obtained for silage in the present study (Kähäri and Paasikallio 1978).

The Cu/Mo ratio is important in livestock nutrition (NJF 1975). Deficiency in Cu can appear, if the Mo content of the feed exceeds 2 mg/kg DM. A high sulphur content in feed (over 0,25 % in DM) increases the risk of Cu deficiency. Rinne et al. (1977) have observed that N fertilization has increased the Cu/Mo ratio of grass and therefore regard moderate N fertilization (200—250 kg/ha/three harvest) reasonable in this respect. In the present study the Mo contents were so low that there was no risk of Cu deficiency due to the Cu/Mo ratio. The sulphur content of some feed samples was determined (Anon 1955). The average content of the nine samples was 0,25 % in DM (variation 0,22—0,31 %), which is higher than the contents obtained from silage samples collected from different parts of the country: 0,14±0,05 % (Kreula and Ettala 1976). No disturbances were observed in the animals. The mineral mixtures fed to cows contained copper. The Cu content of grass could be increased by Cu fertilization (Jaakkola and Vogt 1978).

The average *selenium* (Se) content of grass was 0,014 mg/kg DM, and in silage 0,015 mg/kg DM (Table 4). According to standards (NJF 1975) the Se requirement of cattle is 0,1 mg/kg DM, thus a Se addition in the mineral nutrition was necessary. The lowest Se-contents were obtained at the North Savo and the North Pohjanmaa Experimental Stations, whereas the highest values were obtained in Vantaa. The summer harvest contained less selenium than other harvests.

Table 4. The Se, Mo, and Co contents in the dry matter of grass and its silage.

	Mo ppm				Se ppm				Co ppm			
	Grass		Silage		Grass		Silage		Grass		Silage	
	N	x̄	N	x̄	N	x̄	N	x̄	N	x̄	N	x̄
Experimental stations												
Vantaa	2	0,14	8	0,15	4	0,028	8	0,028	1	0,39	7	0,37
Häme	2	0,72	5	0,65	3	0,021	6	0,014	2	0,19	6	0,20
North Savo	5	0,45	11	0,59	6	0,007	12	0,010	4	0,21	11	0,22
North Pohjanmaa	3	0,18	12	0,30	6	0,007	12	0,013	4	0,20	10	0,26
Lapland	1	0,43	4	0,65	2	0,016	4	0,016	1	0,32	4	0,28
Years												
1971	9	0,24	25	0,31	12	0,011	23	0,017	9	0,22	23	0,29
1972	4	0,68	14	0,63	8	0,016	16	0,014	3	0,24	14	0,24
Mowings												
1st	7	0,27	21	0,33	11	0,015	22	0,016	7	0,26	18	0,30
2nd	3	0,21	8	0,39	4	0,008	8	0,008	4	0,17	6	0,19
3rd	3	0,80	11	0,64	6	0,016	12	0,019	5	0,27	10	0,25
Mean	13	0,38	40	0,43	21	0,014	42	0,015	12	0,22	38	0,26

Statistical analysis was not carried out because of too few samples

The average *cobalt* (Co) content of grass was 0,22 mg/kg DM, and of silage 0,26 mg/kg DM (Table 4). The recommended (NJF 1975) Co content in feed for cattle is 0,1 mg/kg DM. Thus the Co-demand of the animals was satisfied with silage.

The highest Co content obtained at Vantaa, the lowest at the Häme Experimental Station. The Co content of the midsummer harvest was lower than that of other harvests. Differences between years were small. The Co contents of grass samples collected from different parts of Finland were much lower (Kähäri and Paasikallio 1978) than in the grass and silage samples studied here.

The *iodine (I)* content of 17 grass and 42 silage samples was determined, but in some samples (5 grass and 12 silage) the content was below the detection limit (1 mg/kg DM). According to the nutrient recommendations of NJF (1975), the iodine content in the diet DM of livestock should be 0,8—2,0 mg/kg depending on the nitrogen content of the feeds.

Areas poor in iodine were Vantaa and the North Savo Experimental Station, where most of the samples contained less than 1 mg iodine/kg DM. The highest contents were obtained at the North Pohjanmaa Experimental Station, where the I content varied between 1 and 4 mg/kg DM, the average I content of grass being 2,5 mg/kg DM, and of silage 1,75 mg/kg DM. At the Häme and Lapland Experimental Stations the contents varied from below 1 mg to 3—4 mg/kg DM. Signs of iodine deficiency in the thyroid of young calves were most severe in the material obtained from south and east Finland (Kossila et al. 1970) which is in agreement with the results of the present study.

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SELOSTUS

Runsaasti typpilannoitetun ruohon ja siitä valmistettujen tuoresäilörehujen kivennäispitoisuuksista

ELSI ETTALA ja VAPPU KOSSILA

Maatalouden tutkimuskeskus

Verraten runsaasti typpilannoitetusta ruohosta (82 % nurmista sai 60—100 kg N/ha/sato) valmistettiin ruokintakokeita varten säilörehuja vuosina 1971—72 viidessä koepaikassa; Tikkurilan koetilalla sekä Hämeen, Pohjois-Savon, Pohjois-Pohjanmaan ja Lapin koeasemilla. Ruohossa oli raakavalkuaista keskimäärin 19,5 %, säilörehuissa 19,8 %/ka.

Säilörehujen kuiva-aineessa oli keskimäärin kalsiumia 0,27 % ja fosforia 0,32 %. Ca/P-suhde oli keskimäärin 0,8, mitä on eläinten kannalta pidettävä alhaisena (optimi: 1—2). Magnesiumia oli keskimäärin 0,21 %. Kevätkesän säilörehuissa sekä Pohjois-Savon koeaseman rehuissa Mg-pitoisuus jäi alle suositusnormien (0,20 %). Keskimääräinen kaliumpitoisuus oli säilörehussa 2,5 %. K/(Ca+Mg)-ekvivalenttisuhde oli keskimäärin 2,24 ja kevätsadossa 2,78. Viime mainittu ylittää laidunhalvausvaaran merkkinä pidettävän 2,2 rajan. Säilörehun natriumpitoisuus oli keskimäärin 0,04 %, joka eläinten tarpeeseen (0,15 %) nähden on erittäin pieni. Vastaavat pitoisuudet ruohossa olivat: Ca 0,31 %, P 0,39 %, Mg 0,25 %, K 3,26 % ja Na 0,06 %.

Säilörehuissa oli keskimäärin rautaa 0,06 % ja mangaania 97,9 mg, sinkkiä 34,2 mg, kuparia 11,2 mg, molybdeenia 0,43 mg, seleeniä 0,015 mg ja kobolttia 0,26 mg kilossa kuiva-ainetta. Jodipitoisuus vaihteli alle 1 mg:n tasosta 4 mg:aan/kg ka. Sinkki- ja seleenipitoisuudet olivat eläinten suositusnormeihin (Zn 50 mg ja Se 0,1 mg/kg ka) nähden liian alhaisia. Kuparipitoisuus oli alle normin (10 mg/kg ka) pohjoisilla koeasemilla. Jodipitoisuus oli hyvin riittävä Pohjois-Pohjanmaan koeasemalla (norm: 0,8—2,0 mg/kg ka). Jodiköyhimmät alueet olivat Vantaa ja Pohjois-Savon koeasema. Muita mikrokivennäisiä oli eläimille riittävästi. Ruohossa vastaavat mikrokivennäispitoisuudet olivat: Fe 0,05 %/ka, Mn 113,6 mg, Zn 45,1 mg, Cu 11,2 mg, Mo 0,38 mg, Se 0,014 mg Co 0,22 mg/kg ka.

Kivennäisten puutteesta tai epäsuhteesta johtuvia sairauksia ei koe-eläimillä todettu. Vajaukset pyrittiin korvaamaan eläinten kivennäisseoksilla.

ANNALES AGRICULTURAE FENNIAE, VOL. 18: 263—274 (1979)

Seria AGRICULTURA N. 62 — Sarja KASVINVILJELY n:o 62

THE EFFECT OF WEATHER ON YIELD AND DEVELOPMENT OF SPRING WHEAT IN FINLAND

Markku Kontturi

Kontturi, M. 1979. **The effect of weather on yield and development of spring wheat in Finland.** Ann. Agric. Fenn. 18: 263—274. (Agric. Res. Centre, Inst. of Plant Husb., SF-31600 Jokioinen, Finland.)

The effects of weather (rainfall, temperature, radiation) on yield, 1 000-kernel weight, protein content and length of development periods of Ruso spring wheat were studied by correlation analysis. Effective temperature sums were calculated to depict the length of spring wheat development periods. The data was collected from official variety trials on spring wheat at three experimental stations of the Agricultural Research Centre in 1966—78.

Rainfall in June (RA_4) had the strongest effect on grain yield of Ruso spring wheat and the effect of rainfall on yield is shown by the equation $y = a + 94{,}63\,x - 0{,}60\,x^2$ ($R^2 = 0{,}61$) as differences in yield levels between locations were pooled.

There was a significant positive correlation between grain yield and total radiation during the period of grain growth ($r = 0{,}71$). The positive correlation between grain yield and 1 000-kernel weight was highly significant ($r = 0{,}72$), the negative correlation between grain yield and grain protein content was significant ($r = -0{,}53$).

The length of development periods was strongly dependent on temperature. High temperatures, especially in dry years, decreased the length of development periods as shown by correlation coefficients for different development periods: sown to headed, $r = -0{,}81$; headed to ripe, $r = -0{,}91$; sown to ripe, $r = -0{,}87$. Lower yield and lower 1 000-kernel weight were results of shortened development periods. The following effective temperature sums and their threshold temperatures were obtained to depict the length of a particular development period of Ruso spring wheat: sown to headed 480° above 4 °C; headed to ripe 399° above 8 °C; sown to ripe 874° above 6 °C.

Index words: Spring wheat, rainfall, temperature, total radiation, effective temperature sums.

INTRODUCTION

Spring wheat is grown at the edges of wheat cultivation in Finland (Fig. 1). Thus the weather causes large from year to year variations in growth, yield and yield quality of spring wheat. The acreage of wheat in Finland is about 150 000 ha of mainly spring wheat. The main wheat growing area is located in the southern part of the country (Fig. 1) where thermal conditions are most favourable and soil types most suitable for wheat. However there is often a spring

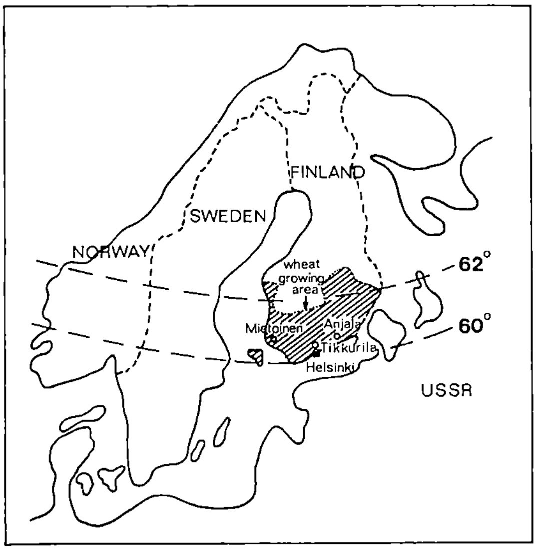


Fig. 1. Wheat growing area in Finland (and locations of three experimental stations of the Finnish Agricultural Research Centre).

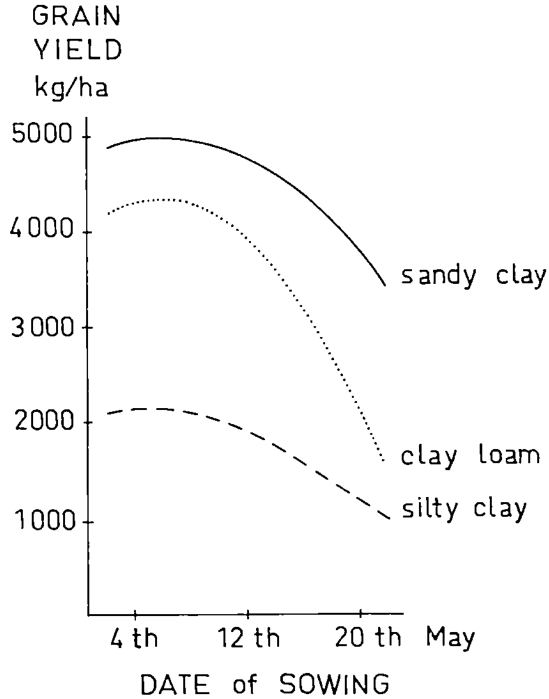


Fig. 2. Effect of sowing time on yield of spring cereals on different soil types (LARPES 1979).

drought in June, at the critical time for yield formation of spring cereals, so the highest yields are obtained from early sowings (LARPES 1979, Fig. 2). Similarly, irrigation (about 30 mm) in the beginning of June has substantially increased spring cereal yields on clay soil (POHJANHEIMO and HEINONEN 1960, ELONEN et al. 1967). However, in July, August and September, as spring wheat ripens and is harvested, rainfall is abundant, which may cause losses in yield and yield quality as the harvest is delayed and made difficult. During cool, wet summers early autumn frosts may also damage the viability of seeds and baking quality of wheat protein as spring wheat needs a long time to ripen. This study, as the earlier one made by POHJANHEIMO (1959), is intended to explain the effects of different weather variables on yield and growth of spring wheat.

MATERIAL AND METHODS

The spring wheat variety Ruso is the most widely grown wheat in Finland. The yield data was collected from official variety trials of spring wheat at the Agricultural Recearch Centre in 1966—78 at three locations: Institute of Plant Husbandry (Tikkurila), South-West Finland Experimental Station (Mietoinen) and Kymenlaakso Experimental Station (Anjala).

Daily observations were used for the rainfall data, but mean pentade temperatures were used for the temperature data. The total radiation data was only available for Tikkurila; radiation observations from Helsinki—Kaisaniemi are used for 1962—71 (20 km south of Tikkurila) and from Helsinki—Vantaa for 1972—78 (10 km west) (Meteorological Yearbook of Finland, Part 4).

Table 1. Data on Ruso spring wheat (average 1966—78)

	Location		
	Tikkurila	Mietoinen	Anjala
	latitude		
	N 60°17′	N 60°38′	N 60°43′
Yield, kg/ha	3 690	3 500	2 760
1 000-kernel weight, g	40,6	39,9	37,3
Protein, % .... (1969—78)	16,1	14,9	16,0
Development			
Date sown	9. May	13. May	15. May
» of emergence	21. May	29. May	27. May
» of headed ..	2. July	4. July	3. July
» of ripe	19. Aug.	22. Aug.	21. Aug.
Period A days sown to headed	53,8	51,9	49,5
Period B days headed to ripe	48,0	49,5	48,8
Period C days sown to ripe ..	101,8	101,5	98,5
Rainfall (mm)			
Period A (RA) ...	64,4	58,5	59,9
Period B (RB) ...	101,7	110,0	107,2
Period C (RC) ...	166,1	169,4	167,2
Mean tempterature (°C)			
Period A (TA) ...	13,2	13,3	13,5
Period B (TB) ...	16,8	16,3	16,3
Period C (TC) ...	14,9	14,7	14,8
Total radiation (MJ/m^2), 1962—78			
Period A (TR A) .	907	—	—
Period B (TR B) .	845	—	—
Period C (TR C) .	1 752	—	—

The experimental stations are located on about the same latitude (Table 1, Fig. 1) and thus possible differences in the growth of spring wheat due to different day lengths are eliminated. The soil type at Tikkurila is sandy clay, at Mietoinen heavy clay and at Anjala silty clay. Variety trials are sown as early as possible (Table 1) to guarantee even emergence and good early growth with spring moisture. The yield data from Mietoinen 1977 was rejected because of exceptionally late sowing.

The use of N fertilizer increased during 1966—78 from about 50 to 90 kg N/ha at Tikkurila, from about 70 to 120 kg N/ha at Mietoinen and from about 60 to 100 kg N/ha at Anjala. The effects of the increase in N fertilizer and placement of fertilizer (introduced in about 1968) are not considered. The following symbols are used for rainfall (R), temperature (T) and total radiation (TR) and for various growth periods of Ruso spring wheat:

A: SOWN TO HEADED

A_1: sown—31st May	(»vegetative period»)
A_2: 1st June—15th June	(30—15 days before headed)
A_3: 16th June—headed	(15—0 before headed)
A_4: A_2+A_3:	(30—0 days before headed or »reproductive period»)

B: HEADED TO RIPE (»grain growth period»)

B_1: headed—20 days after headed

B_2: 20 days after headed—ripe

C: SOWN TO RIPE (total growing time)

The correlation coefficients were calculated between weather variables and yield, 1000-kernel weight, protein content and length of development periods of Ruso spring wheat.

Temperature sums

Temperature sums for different development periods of Ruso spring wheat were calculated by using the method presented by Deputat (1974). It is based on the presumption that in all growth periods hyperbolic dependence occurs between mean temperature and length of each growth period:

$$L = \frac{S}{t-a} \qquad (1)$$

where L is the length of growth period (in days), t is the mean temperature of the period (°C), a the most accurate threshold temperature for the period and S the effective temperature sum (counted above a) for the period (°K). For calculation of a and S, equation (1) is changed to

$$t = a + S\,x \qquad (2)$$

where $x = 1/L$. For the constants a and S and for calculated length (using values a and S) of development period (L) standard deviations (D) were calculated by the method of CRAMER (1946).

RESULTS

Correlation coefficients between different weather variables and yield, 1000-kernel weight, protein content and lenght of different development periods of Ruso spring wheat are presented in Table 2.

Table 2. Coefficients of correlation x 100 (n = 38) (pooled correlations in brackets)

	Yield	1 000 kernel weight	protein %	A sown to headed	B headed to ripe	C sown to ripe
1 000-kernel weight	72^{+++}	—	—	—	—	—
Protein %	—53^{++}	—23	—	—	—	—
A	37^{+}	32^{+}	—14	—	—	—
B	39^{+}	63^{+++}	—22	08	—	—
C	51^{++}	68^{+++}	—25	53^{+++}	89^{+++}	—
RA	36^{+}	41^{++}	—30 (—38^{+})	58^{+++}	41^{++}	62^{+++}
RA_1	—18	—04	10	56^{+++}	—10	17
RA_2	35^{+} (41^{++})	40^{+} (44^{++})	—28 (—26)	27	16	26
RA_3	46^{++} (52^{+++})	32^{+} (36^{+})	—25 (—35)	—07	58^{+++}	46^{++}
$RA_4 = RA_2 + RA_3$	63^{+++} (72^{+++})	54^{+++} (61^{+++})	—40^{+} (—47^{++})	12	59^{+++}	56^{+++}
$RA_4 + RB_1$	41^{++} (49^{++})	54^{+++} (60^{+++})	—12 (—15)	—	54^{+++}	44^{++}
RB_1	14	36^{+} (40^{+})	12	—	33^{+}	21
RB_2	29	25	—10	—	42^{++}	32^{+}
RB	31	39^{+}	—01	—	50^{++}	36^{+}
RC	39^{+}	47^{++}	—11	—	—	53^{+++}
TA	—32^{+}	—38^{+}	21	—81^{+++}	—29	—62^{+++}
TA_1	08	—19	—25	—38^{+}	—11	—27
TA_2	—17	—07	18	—19	14	03
TA_3	—45^{++}	—25	47^{++}	—44^{++}	—44^{++}	—58^{+++}
TA_4	—43^{++}	—22	48^{++}	—44^{++}	—22	—39^{+}
TB_1	—03	—26	31	—	—67^{+++}	—59^{+++}
TB_2	—31	—62^{+++}	25	—	—92^{+++}	—80^{+++}
TB	—21	—52^{+++}	30	—	—91^{+++}	—81^{+++}
TC	—31	—53^{+++}	36	—	—	—87^{+++}

Grain yield

Much of the yield variation between years is explained by rainfall, expecially by rainfall in June (RA_4), r=0,63***. The effect of rainfall varies between locations due to differences in soil types. According to linear regression (Fig. 3 a) rainfall increased the grain yield most at Anjala and less at Tikkurila and Mietoinen. Rainfall in the end of June (RA_3) is more effective, r=0,46**, than rainfall in the beginning of June, r=0,35*, in increasing the grain yield.

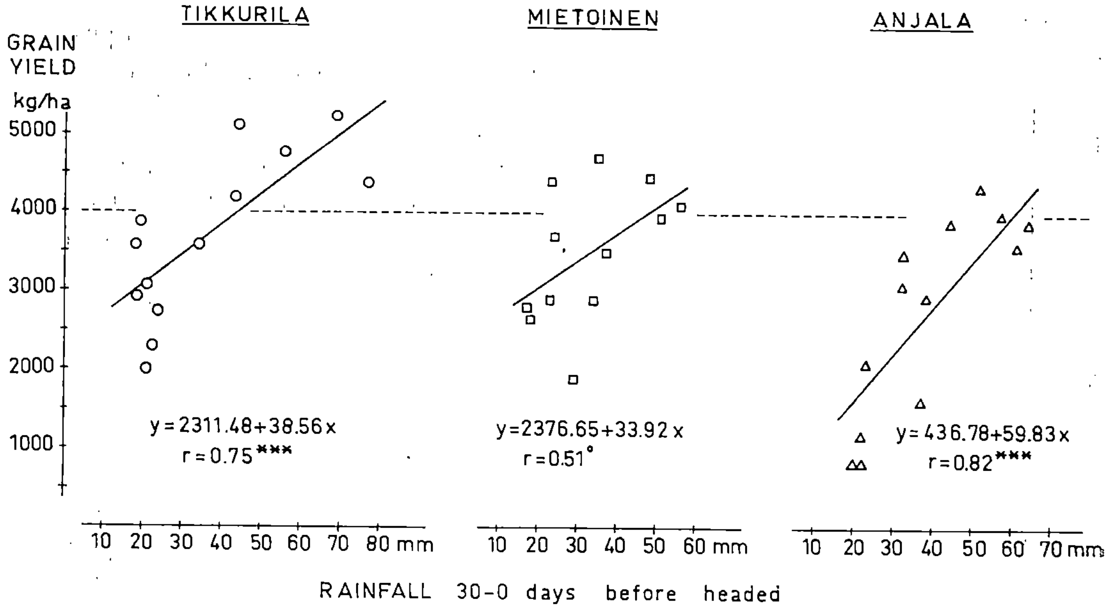
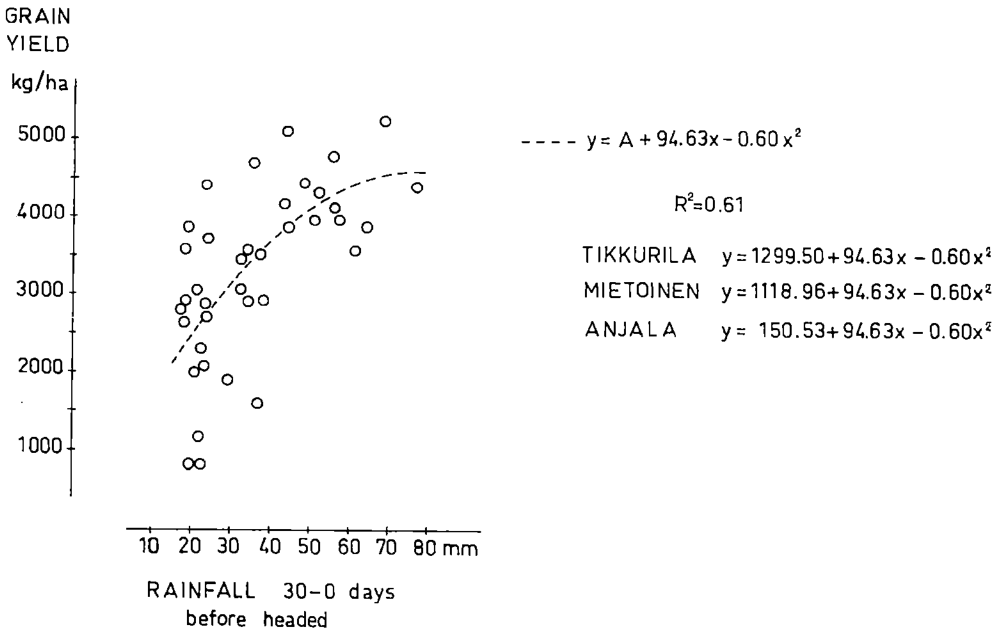


Fig. 3. Effect of rainfall in June (RA_4) on the yield of Ruso spring wheat.
a) linear regressions at different locations



b) pooled regression, all locations

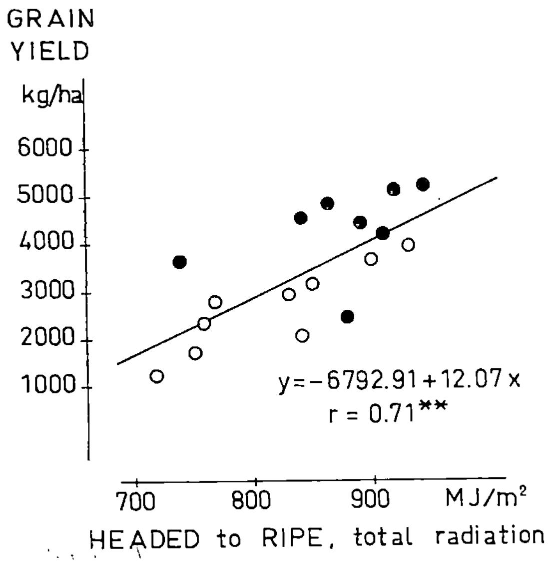


Fig. 4. Effect of total radiation during grain growth (TR B) on yield of Ruso spring wheat (1962—78) at Tikkurila:
● wet years (RA_4>36 mm), ○ dry years (RA_4<35 mm)

When differences in yield levels between locations are pooled, the equation y=a+94,63 x—0,60 x^2 (R^2=0,61) (Fig. 3 b) is obtained for »true rainfall effect» on grain yield. High temperatures in the end of June (TA_3) decrease grain yield, r=-0,45**. Total radiation during grain growth period (TR B) correlates well with grain yield, r=0,71** (Fig. 4). In wet years (RA_4> 36 mm) with the same amount of radiation the grain yield was 1000—1 500 kg higher than in dry years (RA_4 < 35 mm).

1000-kernel weight

Correlation between grain yield and 1000-kernel weight was highly significant r=0,72*** (Fig. 5). High temperatures during grain filling, (TB_2) decreased 1000-kernel weight, r =

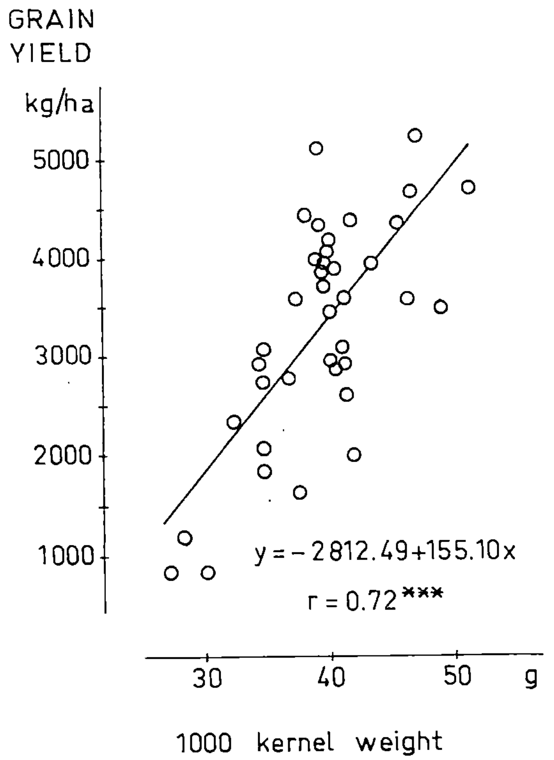


Fig. 5. Effect of 1 000-kermel weight on the grain yield of Ruso spring wheat.

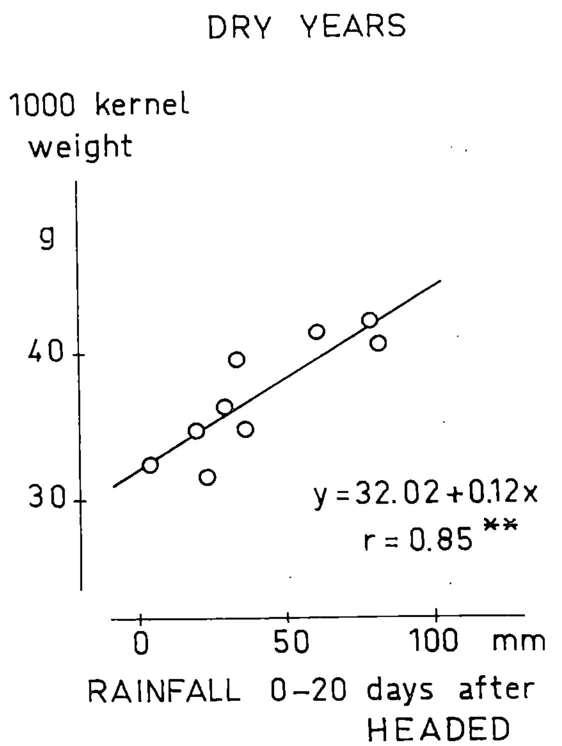


Fig. 6. Effect of rainfall during 20 days after headed on 1 000-kernel weight in dry years (1963—78) at Tikkurila.

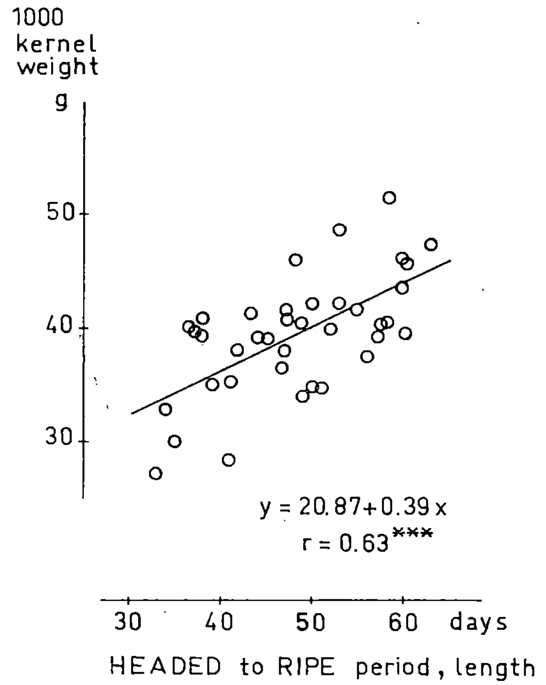


Fig. 7. Effect of the length of grain growth period on 1 000-kernel weight.

-0,62***, whereas rainfall around ear emergence and anthesis (RA_4 and RA_4+RB_1) increased 1000-kernel weight, r=0,54***. Rainfall 20 days after ear emergence (RB_1) increased 1000-kernel weight, r=0,85** (Fig. 6), especially in dry years at Tikkurila. However, best correlations were found between 1000-kernel weight and total growing time, r=0,68***, and period of grain growth, r=0,63***, (Fig. 7).

Protein content

Correlation between grain yield and protein content was weaker, but still significant, r = -0,53*** (Fig. 8) The weather variables studied explained little of the variation in protein content. However rainfall in June (RA_4) seemed to decrease protein content, r=-0,40*, while high temparatures in June (TA_4) seemed to increase protein content, r=0,48**. Furthermore, from the data from Tikkurila, it is obviuos that in wet years high total radiation from emergence to headed (TR A) increases protein content, r=0,73° (Fig. 9).

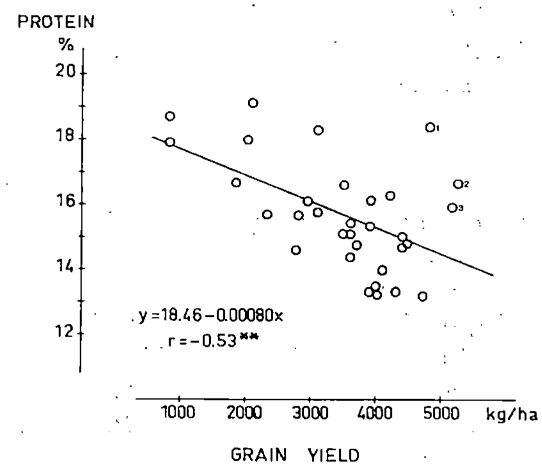


Fig. 8. Effect of grain yield on grain protein content.

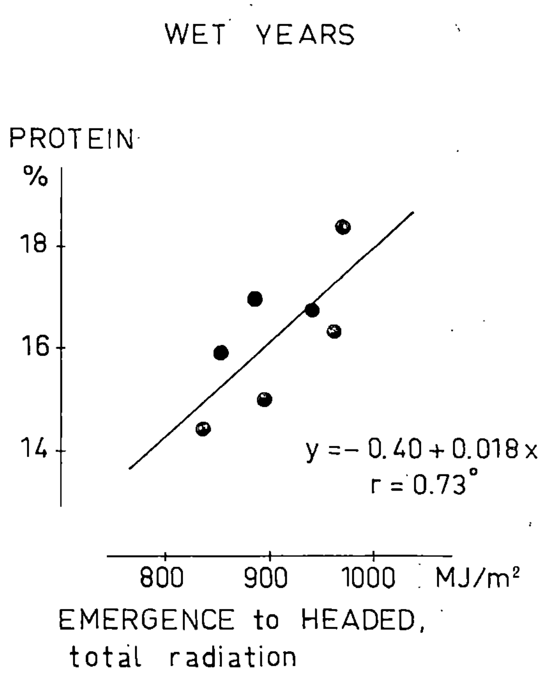


Fig. 9. Effect of radiation during emergence to headed period on grain protein content in wet years (1963—78) at Tikkurila.

The length of development periods

The mean temperature of the development period had a very strong effect on the length of development period, as shown by correlation coefficients for different development periods: period A, r=-0,81***; period B, r=-0,91*** (Fig. 10); and period C, r=-0,87***. Effective temperature sums were calculated to depict the length of development periods. Effective temperature sums and their threshold temperatures for each development period and for different types of years (wet or dry) are shown in table 3. Because of the scanty data the reliability of calculated effective temperature sums in predicting the length of development periods was weak (Table 4). Moisture conditions had no effect on the calculated threshold temperature at phase A, but at phase B and phase C the threshold temperature was much lower in wet years than in dry years. The hyberbola of effective temperature sum for total growing time, $L = \frac{874°,}{t—6°}$ is shown in Fig. 11.

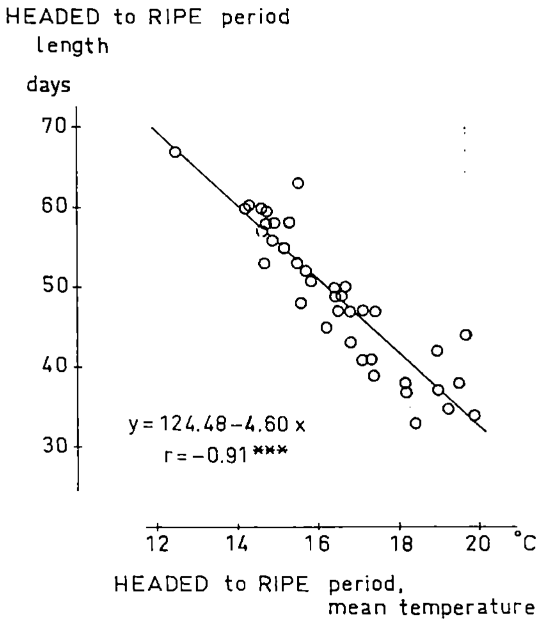


Fig. 10. Effect of mean temperature in headed to ripe period on the length of grain growth period.

Table 3. Thermal thresholds and effective temperaturesums for different development periods of Ruso spring wheat.

	n	R^2	thermal threshold	effective temperature sum (S)	standard deviation of S K°	development periods: mean length days	development periods: mean temp. °C
SOWN to HEADED							
all years	39	0,69	4,31	480 > 4	28,3	51,7	13,4
dry years (RA_4<35 mm)	22	0,80	4,15	483 > 4	28,1	51,4	13,5
wet years (RA_4>36 mm)	17	0,79	4,90	425 > 5	28,6	52,2	13,2
HEADED to RIPE							
all years	39	0,73	8,22	399 > 8	37,0	48,8	16,5
dry years ...	22	0,81	9,75	309 > 10	23,5	44,3	17,2
wet years ...	17	0,76	5,69	510 > 6	44,3	54,5	15,6
SOWN to RIPE							
all years	39	0,60	6,17	874 > 6	45,2	100,5	14,8
dry years ...	22	0,80	6,65	773 > 7	41,2	95,7	15,1
wet years ...	17	0,80	4,21	1 096 > 4	47,9	106,8	14,3

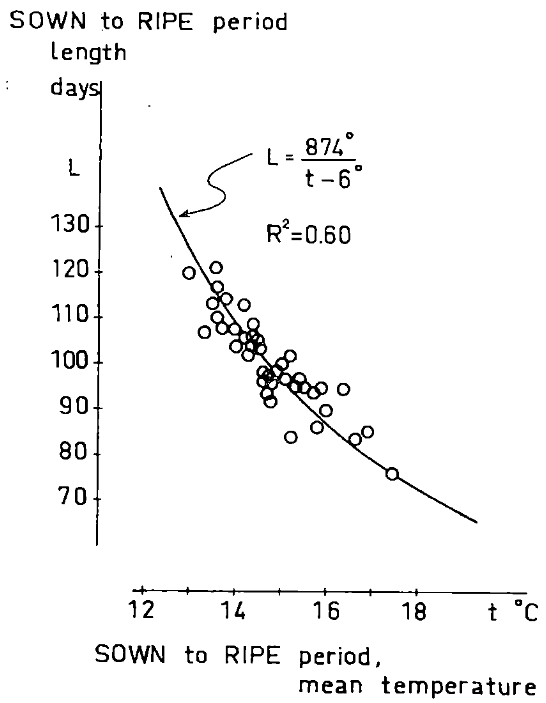


Fig. 11. Effective temperature sum hyberbola for total growing time of Ruso spring wheat.

Table 4. Thermal threshold (a), effective temperature sum (S) estimated from equation (2) and calculated length of development periods (L) and their standard deviations (D) for Ruso spring wheat.

°C	°K	days
SOWN to HEADED		
a = 4,31	S = 464,11	L = 51,34 (t = 13,35)
D(a) = 1,00	D(S) = 51,05	D(L) = 11,39
HEADED to RIPE		
a = 8,22	S = 389,08	L = 46,99 (t = 16,50)
D(a) = 0,68	D(S) = 31,58	D(L) = 7,63
SOWN to RIPE		
a = 6,17	S = 857,04	L = 99,42 (t = 14,97)
D(a) = 0,72	D(S) = 71,66	D(L) = 16,70

DISCUSSION

An adequate vegetative period is required to establish the root system and leaf canopy as a basis for later crop growth. It is also needed to establish the tillers and potential spikelet sites, particularly in temperate cereals where sufficient tillering is important (Evans and Wardlaw 1976). Under Finnish conditions the spring moisture stored in top soil can guarantee even emergence and good early growth of spring wheat from timely sowings (Larpes 1979, Fig. 2). However, during early summer after emergence of the wheat there is often a period of drought (in southern Finland) and this causes low yields (Fig. 3 b). In the beginning of reproductive period ushered in by inflorescence initiation, the rapidly elongating stems and differentiating inflorescences are the main competitors for assimilates, although root growth continues and expansion of the upper leaves is completed (Evans and Wardlaw 1976). If the weather at that time is dry and hot the growth of wheat is retarded.

Water stress strongly decreases net photosyntesis and viable leaf area in corn (Boyer 1976) and in barley (Biscoe and Gallagher 1977). Consequently the competition for assimilates between growing organs of wheat is increased. Salter and Goode (1967) have shown that wheat is very sensitive to water stress during the formation of reproductive organs and during flowering. Fisher (1973) showed that grain yield was most sensitive to water stress at a stage about 10 days before ear emergence, as the number grains per spikelet is then determined. The sensitivity to stress decreased markedly at later or also towards earlier stages of development.

High temperatures, especially if water supply is reduced, around ear emergence and anthesis decrease the yield potential of wheat. High temperatures hasten the development of wheat and cause poor seed-setting (KOLDERUP 1979). High temperatures in this study also caused marked shortening of the development period from sown to headed (Table 2). The nitrogen utilization of cereals is decreased in dry soil (KAILA and ELONEN 1971, REHATTA et al. 1979) and insufficient N availability weakens yield formation in wheat (LANGER and LIEW 1973). Lower N utilization also causes lower N yield, because most of the N harvested in grain is taken up before ear emergence (KOLDERUP 1975, KRAMER 1979). As a consequence of of drought (and high temperatures) the viable leaf area remains low and the source-capacity later during grain growth is not optimal. Furthermore, the number of grains per unit ground area remains low and sink-capacity is not optimal. The weather-yield analysis of this study clearly shows that rainfall in June strongly increases the wheat yield (Fig. 3 a, b). Irrigation during June has same effect on yield (POHJANHEIMO and HEINONEN 1960, ELONEN et al. 1967). Irrigation (or rain) also improves utilization of N by spring wheat (KAILA and ELONEN 1970). Similarly in this study, when the rainfall during early summer was sufficient, high radiation from emergence to headed increased protein content (Fig. 9). With plenty of radiation wheat grew well and the uptake of N to shoot was large (large N pool). Later, during grain growth, N is translocated to the grain (KRAMER 1979).

Grain yield is mainly derived from net photosyntesis during grain growth, and in optimal conditions only a small proportion of carbohydrates in the yield are derived from photosynthates formed before anthesis (EVANS and WARDLAW 1976). The correlation between total radiation during grain growth and grain yield in this study was also positive (Fig. 4). However the sink or storage capacity of assimilates is to a large degree determined earlier by the extend of photosyntesis during the reproductive stage of the crop (EVANS and WARDLAW 1976).

In wet years ($RA_4 > 36$ mm) much higher yields were produced with the same amount of radiation than during dry years ($RA_4 < 35$ mm) (Fig. 4). Obviously this difference in the effect of radiation was a consequence of drought during the reproductive stage, which caused low viable leaf area (low source-capacity) and low grain number per ground area (low sink-capacity), because under Finnish conditions rainfall during grain growth is sufficient and harmful, high temperatures are rare. The above is supported by the regression equation calculated for the effects of rainfall in June (RA_4=x) and radiation during grain growth (TR B=z) on grain yield $y = -3186{,}95 + 29{,}54\ x + 6{,}78\ z$, $R^2 = 0{,}74$.

Cereals have a capacity for yield component compensation, i.e. for the later determined components of grain yield to compensate for earlier losses or to take advantage of favourable conditions later in the life cycle. If grain number per ear in wheat is reduced the remaining grains may grow larger to a certain extent (BINGHAM 1967). PASSIOURA (1976) also showed that the grain of severely stressed wheat was filled largely from reserves, rather than mainly from current photosynthate. In this study 1000-kernel weight was the only yield component for which data was available. Grain yield and 1000-kernel weight correlated well (Fig. 5). In dry years at Tikkurila rainfall during 20 days after headed (RB_1) increased 1000-kernel weight (Fig. 6). However, temperature had the strongest effect on grain growth and 1000-kernel weight by regulating the length of the grain growth period (Fig. 7, Fig. 10). MARCELLOS and SINGLE (1972) showed that high temperature reduces the length of the grain growth period, and thereby decreases the time for photosynthesis and dry matter accumulation into the grains.

High grain yields were low in protein content (Fig. 8). High temperatures and reduced water supply decreased yield but increased protein content (table 2). KOLDERUP (1975) confirmed that high temperatures and reduced watering decreased carbohydrate production more than protein production. However under optimal conditions both yield and protein content may be high, e.g. yields 1, 2 and 3 in Fig. 8. These yields are from wet years when wheat was grown on sandy clay rich in organic matter, and thus water and nutrient supply was unlimited.

The correlations between yield, length of growth periods and temperature and rainfall obtained in this study are similar but stronger than those obtained by POHJANHEIMO (1959) using monthly mean temperature and rainfall data.

Temperature strongly regulates the length of development periods of wheat (table 2, Fig. 10). According to the Polish study (DEPUTAT 1974) there is a hyperbolic dependence between temperature and the length of development period. To attain a certain development stage, wheat requires a determined sum of mean daily temperatures counted above a certain threshold, which is different for each development period. The threshold temperatures of effective temperature sums calculated for Ruso spring wheat (Table 3) are similar to those obtained by DEPUTAT (1974) for Polish spring wheats: sown to headed, in Poland 3°C and Finland 4°C; headed to ripe, 9°C and 8°C; sown to ripe, 4°C and 6°C, respectively (Fig. 11). However, under Finnish conditions rainfall during June (RA_4) affects the threshold temperature obtained for the grain growth period and total growing time (Table 3). It is obvious that by using effective temperature sums calculated from a large amount of data with the above-mentioned method it is possible to predict the occurence of a given development phase of spring wheat rather accurately, especially when the variation in day length before ear emergence of spring wheat within wheat growing areas in Finland is little.

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SELOSTUS

Säätekijöiden vaikutus kevätvehnän satoon ja kasvuun.

MARKKU KONTTURI

Maatalouden tutkimuskeskus

Tutkimuksessa pyrittiin selvittämään säätekijöiden vaikutusta Ruso kevätvehnän satoon, 1 000-jyvänpainoon ja valkuaispitoisuuteen sekä kehitysjaksojen pituuteen laskemalla korrelaatioita Ruson eri kehitysvaiheissa vallinneiden sääolojen (sademäärä, keskilämpötila, kokonaissäteily) ja edellä mainittujen Ruson ominaisuuksien (sato jne.) välillä. Lisäksi kehitysjakson kestoa kuvaamaan määritettiin kullekin jaksolle ominainen tehoisa lämpötilasumma. Havaintoaineisto on koottu Maatalouden tutkimuskeskuksen (Anjala, Mietoinen, Tikkurila) lajikekokeista vuosilta 1966—78.

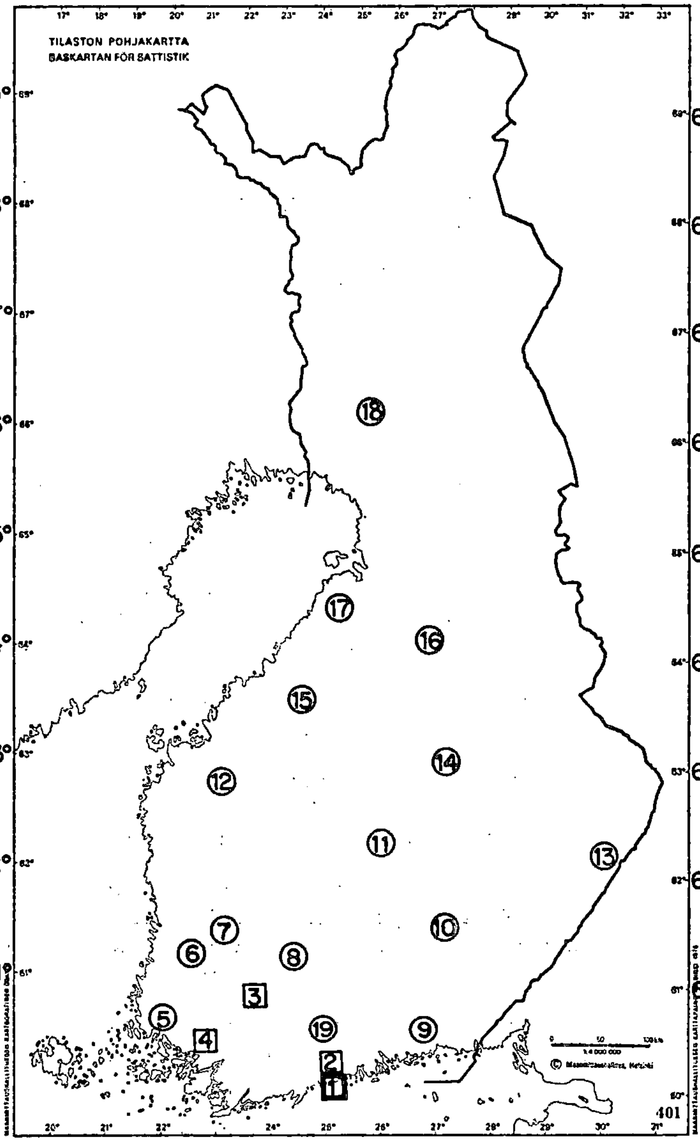
Ruson jyväsatoon vaikutti voimakkaimmin kesäkuun sademäärä, jonka »todelliselle vaikutukselle» koepaikkojen välisen, maalajieroista johtuvan, satotasoeron poistamisen jälkeen saatiin regressioyhtälö (kuva 3 b):
$y = a + 94{,}63\,x — 0{,}60\,x^2$ ($R^2 = 0{,}61$) eli 80 mm:iin saakka kesäkuun sademäärä (RA_4) lisää Ruson satoa.

Jyvänkasvujakson säteilymäärän ja sadon välillä oli merkitsevä positiivinen korrelaatio ($r = 0{,}71$**). Sadon ja 1 000-jyväpainon välillä oli erittäin merkitsevä positiivinen korrelaatio ($r = 0{,}72$***), kun taas sadon ja valkuaispitoisuuden välillä oli merkitsevä negatiivinen korrelaatio ($r = —0{,}53$**).

Kehitysjaksojen pituus riippui voimakkaasti lämpötilasta. Korkeat lämpötilat, etenkin kuivina vuosina, lyhensivät voimakkaasti kehitysjaksojen kestoa. Korrelaatiot eri jaksoilla olivat: kylvö—tähkintä $r = —0{,}81$***; tähkintä—tuleentuminen $r = —0{,}91$***; kylvö—tuleentuminen $r = —0{,}87$***. Kehitysjaksojen lyhentymisen seurauksena sato ja 1 000-jyvänpaino alenivat.

Ruson kehitysjaksojen pituutta kuvaamaan saatiin seuraavat tehoisat lämpötilasummat ja kynnyslämpötilat: kylvö—tähkintä 480° > 4 °C; tähkintä—tuleentuminen 339° > 8 °C; kylvö—tuleentuminen 874° > 6 °C.

Aikaisella kylvöllä ja kuivina keväinä kesäkuun puolessa välissä suoritetulla sadetuksella voidaan kevätvehnän satoa savimailla kohottaa ja pienentää vuosien välisiä satovaihteluja.



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