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Cadmium and lead levels in Norwegian vegetables

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The purpose of this study was to present the levels of concentration of cadmium and lead in vegetables grown in Norway. The mean concentrations were found to be within the same levels as those for vegetables from some other European countries. There were, however, higher concentration levels in vegetables grown in the southernmost part of the country compared with vegetables from Central Norway. It was found that the levels of concentration were higher early in the growing season. Paring carrots lowered the concentration of lead by about 50%. Washing Chinese cabbage in deionized water did not lower the concentration of cadmium or of lead. A reasonable consumption of these vegetables does not constitute a health risk for the consumer, based on the FAO/WHO provisional tolerable weekly intake of cadmium and lead. This study, however, shows that several factors may have a great influence on the intake of heavy metals through a vegetable diet.

Key words: Cadmium, heavy metals, lead, vegetables.

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The situation concerning heavy metal air pollution in Norway on a national basis has been extensively studied. The deposition of many elements is significantly higher in the southern and southwestern parts of the country than in areas further north. A great part of this deposition is due to long-distance atmospheric transport from other parts of Europe (Allen & Steinnes 1980; Rambæk & Steinnes 1980).

The possible influence of this long-distance atmospheric transport on agricultural products has not been appreciably examined in the past.

The absorption of metals through the soil is influenced by factors such as the pH of the soil, the organic matter content, interaction of other metals and by the crop itself. In this way the growing system acts as a buffer which interferes with the effects of pollution.

The aim of this study was to show the levels of concentration of cadmium and lead in different vegetable crops grown in the southernmost and central parts of the country.

MATERIAL AND METHODS

The samples were collected from four fields with different locations, pH and organic matter content (Table 1.) Each field consisted of four crops replicated in four blocks. The crops were randomized within each block. The plot size was 13 m^2. The crops were: white cabbage, carrot, Chinese cabbage and celery. The level of fertilization was 1500 kg ha^{-1} (carrot 1000 kg ha^{-1}) containing 11% N,

Table 1. Location, organic matter content, pH and concentration of cadmium and lead in soil samples from four research fields (0- 20 cm depths)

Site	Location	% organic C	pH	mg kg $^{-1}$ dry weight Pb	Cd
1	Stjørdal/Central	8.3	6.0	30	.05
2	Grimstad/South	1.7	5.5	18	.16
3	Grimstad/ »	1.7	6.5	19	.11
4	Grimstad/ »	20.0	5.3	34	.11
P (site)				ns.	<0.001

5% P and 17% K. Each crop was harvested three times at two-week intervals (one-week intervals for Chinese cabbage).

The plant samples were not washed, with the exception of Chinese cabbage, for which the effect of washing in deionized water was studied. The soil samples were collected once from all plots early in the growing season. A total of 60 soil samples and 300 vegetable samples were collected.

For analysis of soil samples, a treatment with HNO_3 /HCl was used. The concentrations were determined using a graphite furnace atomic absorption spectrophotometer. The dried crop samples were digested at 450° C. The determinations were performed with a graphite furnace atomic absorption spectrophotometer using an argon flame.

RESULTS

The concentrations of cadmium and lead in the soil are presented in Table 1. The samples from Central Norway had a lower content of cadmium than soil samples from the Grimstad area in the south. This difference was not found for lead.

Table 2 shows the effect of site, crop and time of harvest on the concentration levels of cadmium. In white cabbage and in Chinese cabbage the concentration levels were significantly lower in vegetables from the Trøndelag area than in the Grimstad area. The same tendency, although not significant, was found in carrots and celery, which also had a lower mean concentration of cadmium than the leafy vegetables. The concentration levels were highest at the first harvest. The differences between sites were mainly at the first harvest, especially in the leafy vegetables. The rise in

Table 2. Cadmium content in various vegetable crops throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	White cabbage				Carrots				Chinese cabbage				Celery			
Harvest:	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
Site																
1	0.07	0.08	0.05	0.07	0.13	0.09	0.14	0.12	0.27	0.16	0.17	0.20	0.11	0.32	0.10	0.18
2	3.54	0.06	0.07	1.22	0.52	0.37	0.30	0.40	4.33	0.12	0.19	1.55	0.32	0.59	0.50	0.47
3	1.86	0.06	0.06	0.66	0.45	0.34	0.27	0.35	3.80	0.12	0.18	1.40	0.22	0.39	0.32	0.31
4	3.70	0.05	0.04	1.26	0.40	0.36	0.36	0.37	3.99	0.13	0.19	1.44	0.33	0.68	0.26	0.42
Mean	2.29	0.06	0.06	0.80	0.37	0.29	0.27	0.31	3.10	0.13	0.18	1.14	0.24	0.49	0.30	0.34

LSD 5%: Site: 0.36*** Crop: 0.36*** Harvest: 1.08***

pH from 5.5 to 6.5 in the same type of soil decreased the uptake of cadmium in white cabbage.

The lead content is presented in Table 3. In spite of the relatively high content of lead found in the soil samples, the mean concentration levels of lead were significantly lowest in vegetables from the Trøndelag area. Also in the case of lead the concentration levels tended to be highest after early harvest. The leafy vegetables had the lowest content. The difference in pH between sites 2 and 3 did not affect the concentration of lead in the plant samples.

Washing Chinese cabbage and paring carrots did not decrease the content of cadmium in these products (Tables 4 and 5). Nor was the concentration of lead reduced by washing the Chinese cabbage. On the other hand, the mean content of lead in carrots was lowered by approximately 50% when the brushed carrots were pared (Tables 6 and 7).

DISCUSSION

The significance of the soil factors on the accessibility of the plants to heavy metals can be expressed in terms of quantity and quality, where a certain concentration in the soil may cause different uptake in the plants due to differences in mobility in soils.

In general, heavy metals have a low mobility in soils. This can be seen when comparing the concentrations in soils at various depths. The levels of concentration in the soil samples from this

Table 3. Lead content in various vegetable crops throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	White cabbage				Carrots				Chinese cabbage				Celery			
Harvest	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean	1	2	3	Mean
Site																
1	0.05	0.04	0.69	0.26	0.75	0.16	0.24	0.38	1.86	0.08	0.07	0.57	0.32	1.37	1.61	1.10
2	1.00	0.52	0.04	0.52	1.90	1.35	1.65	1.63	0.58	0.05	0.09	0.24	3.65	1.50	1.90	2.35
3	0.46	0.44	0.03	0.31	1.89	1.08	1.62	1.53	1.50	0.05	0.08	0.54	2.92	1.88	1.96	2.25
4	1.27	0.79	0.03	0.70	3.15	1.69	2.98	2.60	2.63	0.07	0.06	0.92	3.11	2.56	2.72	2.80
Mean	0.70	0.45	0.20	0.45	1.92	1.07	1.62	1.54	1.64	0.06	0.08	0.59	2.50	1.83	2.05	2.13

LSD 5% Site: 0.45*** Crop: 0.41*** Harvest: 1.08***

Table 4. Cadmium content in pared and unpared carrots throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	Unpared				Pared			
Harvest	1	2	3	Mean	1	2	3	Mean
Site								
1	0.13	0.09	0.14	0.12	0.19	0.12	0.11	0.14
2	0.52	0.37	0.30	0.40	0.55	0.34	0.24	0.38
3	0.45	0.34	0.27	0.35	0.31	0.29	0.22	0.27
4	0.40	0.36	0.36	0.37	0.36	0.32	0.34	0.34
Mean	0.38	0.29	0.27	0.31	0.33	0.27	0.23	0.28

LSD 5% Paring: ns.

Table 5. Cadmium content in washed and unwashed Chinese cabbage throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	Unwashed				Washed			
Harvest	1	2	3	Mean	1	2	3	Mean
Site								
1	0.27	0.16	0.17	0.20	0.29	0.18	0.18	0.22
2	4.33	0.12	0.19	1.55	4.36	0.11	0.22	1.56
3	3.80	0.12	0.18	1.40	4.01	0.13	0.12	1.42
4	3.99	0.13	0.19	1.44	3.59	0.15	0.17	1.30
Mean	3.10	0.13	0.18	1.14	3.06	0.14	0.17	1.12
LSD 5%	Washing: ns.							

Table 6. Lead content in pared and unpared carrots throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	Unpared				Pared			
Harvest	1	2	3	Mean	1	2	3	Mean
Site								
1	0.75	0.16	0.24	0.38	0.82	0.10	0.07	0.33
2	1.90	1.35	1.65	1.63	1.54	0.69	0.94	1.06
3	1.89	1.08	1.62	1.53	0.76	0.64	0.10	0.50
4	3.15	1.69	2.98	2.60	1.70	1.17	1.02	1.30
Mean	1.92	1.07	1.62	1.54	1.21	0.65	0.53	0.80
LSD 5%	Paring: 0.54***							

Table 7. Lead content in washed and unwashed Chinese cabbage throughout the growing season 1988. Mg kg $^{-1}$ dry weight

	Unwashed				Washed			
Harvest	1	2	3	Mean	1	2	3	Mean
Site								
1	1.86	0.08	0.07	0.67	1.51	0.05	0.05	0.54
2	0.58	0.05	0.09	0.24	0.83	0.06	0.07	0.32
3	1.50	0.05	0.08	0.54	1.39	0.05	0.07	0.50
4	2.63	0.07	0.06	0.92	2.28	0.06	0.10	0.81
Mean	1.64	0.06	0.07	0.59	1.50	0.06	0.07	0.54
LSD 5%	Washing: ns.							

study at 0-20 cm depths from the Trøndelag and Grimstad areas were 0.05 ppm Cd, 30 ppm Pb and 0.11-0.16 ppm Cd, 18-34 ppm Pb, respectively. The levels of concentration in soil samples collected by Allen & Steinnes (1980) at 5 cm depths

from the Trøndelag and Grimstad areas were respectively, 0.20 ppm Cd, 15 ppm Pb and 1.07 ppm Cd, 107 ppm Pb. Also the cultivation of soils dilutes the concentration of heavy metals in the upper soil layers. This may be of particular significance for lead because of a lower downwards movement compared to cadmium (Legret et al. 1988). In this investigation the ratio Pb/Cd was approximately 200 in the soil compared with approximately 2 in the plants. This is also an indication of differences in mobility.

The acceptable levels of concentration of heavy metals in soils will depend upon type of soil and type of crop. In the Netherlands the proposed maximum acceptable Cd concentration for sandy soil is 0.3 ppm (Kongshaug 1989). The levels in this study were 0.11-0.16 ppm Cd. When there is an accumulation then the levels of acceptable concentration in soils would have to be considered.

The mean levels of concentration were highest in plant samples from sites in the south. This was particularly evident at the first harvest. It is reasonable to assume that this is an effect of the contribution from long-range atmospheric transport to the heavy metal pollution of the surface soil in the southernmost part of the country.

On sandy soils the uptake of cadmium decreased when the pH was raised from 5.5 to 6.5. This has also been demonstrated earlier by Wichmann & Knösel (1983) and van Lune (1985).

Previous investigations have pointed out fluctuations in the concentration levels of heavy metals in plants throughout the growing season. A dilution effect attributable to increases in the plant mass may be an explanation for this. Czuba & Hutchinson (1980) found a higher content of lead in the spring than in the autumn in several vegetable crops. Increased growth rate by means of nitrogen fertilization gave enhanced uptake of cadmium in lettuce (Singh et al. 1988).

The highest content of cadmium was found in crops with a large leaf area, as white cabbage and Chinese cabbage. This is in accordance with previous studies (Fritz et al. 1977; Hansen & Andersen 1983; Brune 1984; Wiersma et al. 1986; Sillanpää et al. 1988). Celery is a slow growing crop, and the fairly long period of exposure may be the reason for the rather high content of lead in this vegetable.

It is well known that paring carrots reduces the content of lead (Collett 1978; Brune 1983; Thornton & Jones 1984). In this study the effect of paring also involves removal of some soil particles from the brushed carrots.

The results after washing Chinese cabbage do not indicate any heavy metal deposits on the leaves. It is therefore reasonable to assume that the differences in levels of concentration in the plant samples were due to absorption from the soil. This assumption does not support the viewpoints in some other papers, which conclude that most of the cadmium and lead in crops is airborne, and that a relatively small portion is absorbed by the roots from the soil (Hårdh 1977; Hovmand et al. 1983; Sillanpää et al. 1988).

Table 8 presents the results obtained in the study together with mean values from other countries. The concentrations obtained are within the levels normally found in vegetables.

It is concluded that a reasonable consumption of the vegetables used for this study does not pose a health risk for the consumer, based on the FAO/WHO provisional tolerable weekly intake of cadmium and lead, which is 0.5 mg Cd and 3 mg Pb per 60 kg of mean body weight. Several factors may, however, have a great influence on the intake of heavy metals through a vegetable diet. These need further investigation.

Table 8. Heavy metal content in vegetables in various countries. Mg kg $^{-1}$ dry weight

Crop	n	Min. - Max.	Mean	Country	Literature
Cadmium					
White cabbage	48	0.07 - 1.26	0.80	Norway	This study
	42	<0.1 - 0.6	0.16	Denmark	Hansen & Andersen, 1983
	6	-	<1	Germany	Fritz et al. 1977
	86	0.01 - 0.20	0.06	The Netherlands	Wiersma et al. 1986
Carrots	48	0.12 - 0.37	0.31	Norway	This study
	14	0.6 - 4.4	1.8	Great Britain	Min.Agr.Fish.Food 1973
	100	0.06 - 1.97	0.49	The Netherlands	Wiersma et al. 1986
Chinese cabbage	48	0.20 - 1.44	1.14	Norway	This study
Celery	48	0.18 - 0.47	0.34	Norway	This study
Lead					
White cabbage	48	0.26 - 0.70	0.45	Norway	This study
	42	<0.4 - 1.8	0.2	Denmark	Hansen & Andersen, 1983
	6	-	14.9	Germany	Fritz et al. 1977
	86	0.02 - 2.7	0.18	The Netherlands	Wiersma et al. 1986
Carrots	48	0.33 - 1.30	0.80	Norway	This study
	9	-	0.25	Finland	Sillanpää et al. 1988
	15	0.2 - 2.4	0.8	Great Britain	Min.Agr.Fish.Food, 1975
	100	0.14 - 2.59	0.62	The Netherlands	Wiersma et al. 1986
Chinese cabbage	48	0.67 - 0.92	0.59	Norway	This study
Celery	48	1.10 - 2.80	2.13	Norway	This study

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Iron chlorosis in oats grown in peat soil in relation to concentration of some chemical elements in the crop

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Sorteberg, A. 1990. Iron chlorosis in oats grown in peat soil in relation to concentration of some chemical elements in the crop. Norwegian Journal of Agricultural Sciences 4: 103-109. ISSN 0801-5341.

Pot experiments with sphagnum peat soil, pH about 5, resulted in iron chlorosis in oats and a reduced yield. It was observed that an increase in Ca-content in the fertilizer leads to marked reduction in chlorosis and to an increase in yield. Fe-concentration in the crop was highest for fertilizer rich in Ca only in young plants. Chlorotic plants had a distinctly higher P-concentration than plants without chlorosis. Increasing the amount of Ca in the fertilizer reduced the concentration of P in the crop. The addition of different Fe-rich compounds had a varying effect in eliminating the chlorosis, Fe-EDTHA chelate being the most effective compound.

Key words: Calcium, iron, iron chlorosis, iron-rich compounds, oats, pH, phosphorus.

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Interveinal chlorosis attributable to iron defiency has been observed in pot experiments with oats grown in sphagnum peat soil (Oedelien 1945). This same type of chlorosis in oats and different grass crops was later observed in both pot and field experiments (Sorteberg 1947, and 1961).

In practical plant growing, oats and timothy have been particularly susceptible to chlorisis. However, factors such as physical conditions and lime status of the soil may have some influence over this. For example crushed iron-rich slag mixed in the soil and ferro sulphate sprayed on the leaves are very effective in preventing chlorosis.

In the period 1976-1978 a pot experiment with peat soil indicated a positive effect of calcium in fertilizers in preventing chlorosis in oats, barley and ryegrass. Chemical analysis of the crops showed no significant differences in Fe-concentration between the different fertilizers (Sorteberg 1979, 1980). These findings led to a continuation of the experiment, but this time with some modifications to the original experimental design.

MATERIAL AND METHODS

The experimental design has been described previously by Sorteberg (1979, 1980). In the present study from the period 1979-1980, the design was changed and concomitantly more emphasis paid to the chemical analysis of the crop. The design for growing oats in 1979 included

the following treatments with 5 litre pots:

Low liming
Ca-free mixed fertilizer 0 mg Ca per pot, pH 5.0
Ca-low complex " 70 " Ca " " , pH 5.0
Ca-high mixed " 950 " Ca " " , pH 5.2

High liming
Ca-free mixed fertilizer 0 mg Ca per pot, pH 5.7
Ca-low complex " 70 " Ca " " , pH 5.7
Ca-high mixed " 950 " Ca " " , pH 6.1

Each treatment was carried out with six parallels and with the addition of 587 mg N + 147 mg P and 600 mg K per pot. Suitable and equal amounts of B, Cu, Mn and Mo were added to all the pots. The crop was harvested at three different times:

Two parallels harvested 21 days after germination
One parallel " 28 " " "
Three parallels " 38 " " "
(At ear emergence).

In 1980 the experimental design of the study was changed once more. The high-limed pots were discontinuated, and nine pots with low-limed soil used in the experiment in the period 1976-1978, and representing Ca-free, Ca-low and Ca-high fertilizers, were included in the experiment. The soils for each rate of Ca were mixed thoroughly and a study containing the following series was carried out:

9 parallels of Ca-free fertilizer
9 " " Ca-low "
9 " " Ca-high "

In addition each pot was given the standard dressing of N, P and K and was further supplemented with iron-rich compounds as is the case for every series of Ca-containing fertilizer:

Control
5.000 g crushed iron-slag = 2000 mg Fe
0.250 g $FeSO_4 \cdot 7H_2O$ = 50 " Fe
0.500 g $FeSO_4 \cdot 7H_2O$ = 100 " Fe
0.309 g Fe-EDTA chelate = 45 " Fe
1.483 g Fe-EDTA chelate = 216 " Fe
1.483 g Fe-EDTHA chelate = 249 " Fe

There were two parallels for control and iron-rich slag, but no replicate for the other treatments. The iron compounds were incorporated in the soil. In 1980 the crop was harvested at ear emergence.

RESULTS

Oats were grown in both 1979 and 1980. In 1979 the low limed plants combined with the Ca-free fertilizer showed severe chlorosis. Less severe chlorosis was observed when a fertilizer low in Ca was used. With heavy liming only slight chlorosis was observed with the identical treatment, while no chlorosis was observed with the Ca-high fertilizer.

Yield size and the Fe concentration in dry matter are given in Table 1. Dif-

Table 1. Oats 1979. Yields of dry matter per pot and Fe in dry matter at three harvesting times

Harvested, days after germination	Yield, DM per pot / Fe, mg/pot	Low liming Fertilizers Ca-free	Ca-low	Ca-high	High liming Fertilizers Ca-free	Ca-low	Ca-high
21	DM, g/pot	10.2	12.6	14.7	14.3	12.1	14.2
	Fe, mg/kg	43	49	56	50	47	59
28	DM, g/pot	16.0	21.9	28.9	26.7	34.1	23.9
	Fe, mg/kg	35	41	40	44	37	31
38 (At ear emergence)	DM, g/pot	30.2	50.6	53.6	52.4	55.2	50.6
	Fe, mg/kg	27	27	28	27	21	17

ferences in yield observed at harvesting 21 and 28 days after germination (parallels two and one respectively) might be random. In the harvest at ear emergence (three parallels), however, at low liming the yield of the Ca-free fertilizer was significantly lower than those of the Ca-high and Ca-low fertilizers. For all fertilizers there was a marked decrease in Fe-concentration in dry matter with time. The concentrations of Ca and P in dry matter are presented in Tables 2 and 3, respectively. The ratios for P/Fe and P/Ca are given in Table 4.

The degree of chlorosis present in the 1980 yield was partly dependent on the calcium content of the fertilizers (Ca-free, Ca-low or Ca-high fertilizers) and partly on the supply of iron-rich compounds. Most of the pots receiving Ca-high fertilizer had normal green plants, but a weak chlorosis in the first part of the growing period was observed for the control and for iron-rich slag. Normal

Table 2. Oats 1979. Percentage Ca in dry matter at three harvesting times

Harvested, days after germination	Low liming Fertilizers			High liming Fertilizers		
	Ca-free	Ca-low	Ca-high	Ca-free	Ca-low	Ca-high
21	0.62	0.55	0.80	0.74	0.66	0.67
28	0.66	0.58	0.67	0.71	0.56	0.53
38	0.63	0.43	0.50	0.55	0.45	0.43

Table 3. Oats 1979. Percentage P in dry matter and mg/pot at three harvesting times

Harvested, days after germination	P in the crop	Low liming Fertilizers			High liming Fertilizers		
		Ca-free	Ca-low	Ca-high	Ca-free	Ca-low	Ca-high
21	% in DM	0.95	0.91	0.75	0.84	0.61	0.44
	mg/pot	97	115	110	120	74	62
28	% in DM	0.74	0.64	0.47	0.50	0.33	0.29
	mg/pot	118	140	136	134	113	69
38	% in DM	0.49	0.30	0.29	0.29	0.20	0.19
	mg/pot	148	152	155	152	110	96

Table 4. Oats 1979. Ratios for some elements in crops at three harvesting times

Ratios	Harvested, days after germination	Low liming Fertilizers			High liming Fertilizers		
		Ca-free	Ca-low	Ca-high	Ca-free	Ca-low	Ca-high
P/Fe	21	221	186	134	168	130	75
	28	211	156	118	114	89	94
	38	181	111	104	107	95	112
P/Ca	21	1.53	1.65	0.94	1.14	0.92	0.66
	28	1.12	1.10	0.70	0.70	0.59	0.55
	38	0.78	0.70	0.58	0.53	0.44	0.44

green-coloured plants were also observed when Fe-EDTHA chelate was added along with the Ca-free and Ca-low fertilizers. A high rate of Fe-EDTA chelate, however, gave weak symptons of chlorosis. For all other treatments some degree of chlorosis occurred in the following order: control > iron-rich slag > ferro sulphate low amount > ferro sulphate high amount > Fe-EDTA chelate low amount. The chlorosis was usuallly more marked for Ca-free fertilizer than for Ca-low fertilizer.

The 1980 yield sizes are presented in Table 5. Apart from the findings when Fe-EDTHA chelate was used, the Ca-free fertilizer produced distinctly lower yields than the Ca-high and Ca-low fertilizers. However, the yield for the Ca-low fertilizer was about the same as that for the Ca-high fertilizer despite of the chlorosis being only slightly lower than for the Ca-free fertilizer. The concentrations of Fe, Ca and P in dry matter are presented in Table 6 and the ratios of P/Fe and P/Ca in Table 7.

DISCUSSION

In both years low liming combined with Ca-free fertilizer led to iron chlorosis and reduced yield, while a crop of normal size, free or nearly free of chlorosis, was obtained when a Ca-high fertilizer was used. Fertilizers low in Ca may be cha-

Table 5. Oats 1980. Harvested at ear emergence, g of dry matter per pot. Parallels only for control and slag. Low liming

Added Fe, mg/pot in different compounds			Fertilizers Ca-free	Ca-low	Ca-high
Control			22.5	36.8	37.8
Iron-rich slag	2000	mg	28.6	39.7	39.4
$FeSO_4 \cdot 7\ H_2O$	50	"	30.9	38.4	39.9
"	100	"	31.5	39.2	37.0
Fe-EDTA chelate	45	mg	31.8	37.6	39.0
"	216	"	36.1	40.2	42.3
Fe-EDTHA chelate	249	"	45.2	45.6	45.0
Average			30.2	38.7	39.2

Table 6. Oats 1980. Fe, Ca and P, mg per kg dry matter. Low liming

Added Fe, mg/pot in different compounds			Fertilizers Ca-free			Ca-low			Ca-high		
			Fe	Ca	P	Fe	Ca	P	Fe	Ca	P
Control			23	0.60	1.01	25	0.46	0.59	34	0.51	0.43
Iron-rich slag	2000	mg	26	0.55	0.73	27	0.42	0.53	32	0.51	0.39
$FeSO_4 \cdot 7\ H_2O$	50	"	26	0.49	0.72	27	0.41	0.61	33	0.46	0.44
"	100	"	31	0.45	0.65	34	0.39	0.55	40	0.52	0.48
Fe-EDTA chelate	45	"	38	0.39	0.67	37	0.40	0.59	39	0.51	0.49
"	216	"	87[1]	0.42	0.65	48[1]	0.34	0.49	46[1]	0.49	0.35
Fe-EDTHA chelate	249	"	34	0.27	0.45	32	0.29	0.45	30	0.36	0.28
Average			38	0.45	0.70	33	0.39	0.54	36	0.48	0.41

[1] Unreasonably high content

Table 7. Oats 1980. Ratios of P/Fe and P/Ca in crops when adding different iron compounds. Low liming

Ratios	Added Fe, mg/pot in different compounds		Fertilizers Ca.free	Ca-low	Ca-high
P/Fe	Control		439	236	126
	Iron-rich slag	2000 mg	281	196	122
	$FeSO_4 \cdot 7\,H_2O$	50 "	277	226	133
	"	100 "	210	162	120
	Fe-EDTA chelate	45 "	176	159	126
	"	216 "	75[1]	102[1]	76[1]
	Fe-EDTHA chelate	249 "	132	141	193
P/Ca	Control		1.68	1.28	0.84
	Iron-rich slag	2000 mg	1.33	1.26	0.76
	$FeSO_4 \cdot 7\,H_2O$	50 "	1.47	1.49	0.96
	"	100 "	1.44	1.41	0.92
	Fe-EDTA chelate	45 "	1.72	1.48	0.96
	"	216 "	1.55	1.44	0.71
	Fe-EDTHA chelate	249 "	1.67	1.55	0.78
	Average		1.55	1.42	0.85

1) Unreasonably high content of Fe

racterized as intermediate. With high (fair) liming, however, chlorosis was no problem.

The yield in relation to concentration of Fe in the crop is unclear. In 1979, at harvesting 21 days after germination, the concentrations of Fe at low liming for Ca-high, Ca-low and Ca-free fertilizers were 56, 49 and 43 mg/kg DM respectively (Table 1), while the concentration was reduced for all kinds of fertilizers, and the succession partly changed seven days later. When harvesting at ear emergence the concentrations of Fe had dropped still more, and were fairly much the same for the different fertilizers. The results indicate that the high concentration of Fe for Ca-high fertilizer until about 20 days after germination may be an important factor in preventing chlorosis. However, the Fe-concentration in the crop in 1980, harvested at ear emergence, was distinctly lower for Ca-free and Ca-low fertilizers than for Ca-high fertilizer even at moderate iron supply (Table 6). As ear emergence does not occur at an exact juncture in a crop such as oats, it might thus be that the evaluation of this biological juncture has varied during the two years. Thus a comparison of the crop size at the last harvesting in 1979 (Table 1, low liming) and for the control in 1980 (Table 5), both without Fe-addition and both harvested at ear mergence, shows a markedly higher yield in 1979 than in 1980. This may indicate that the oats in fact varied in development over the two years. It should be noted that the oats had been grown in greenhouses without heating or any temperature regulation. A direct comparison of the crops for these two years may therefore be doubtful. With high liming in 1979 (Table 1) there seems to be no relation between yield size and the Fe-concentration in the yield or the Ca-content in the fertilizers. Different iron compounds added to the soil had a varied effect in reducing the chlorosis and increasing the yield of oats in 1980 (Table 5) The highest yield was obtained when EDTHA chelate was used, but EDTA chelate with a 13% lower Fe supply had a good effect, too. Iron-rich slag has not been effective in this short-term experiment, despite the high amount of added Fe. However, earlier

field and pot experiments have shown that the iron in the slag does not give full effect in the first year because of low availability (Sorteberg 1947, 1961).

The concentration of Ca in the crop in 1979 at low liming indicates roughly the same pattern as for Fe, with clearly the highest concentration for Ca-high fertilizer occurring at the first harvesting only (Table 2). High liming results in the concentration for Ca being higher for the Ca-free fertilizer than for Ca-high and Ca-low fertilizers at all harvests. This result contrasts somewhat with the results from pot experiments with oats grown in peat soil from another locality with a higher density and higher pH, but also predisposed to iron chlorosis. In this experiment, also harvested at ear emergence there was a marked increase in the concentration of Ca in the crop with increasing rates of lime, increasing rates of $Ca(H_2PO_4)^2$ and with increasing rates of $Ca(NO_3)^2$ (Sorteberg, A. 1970).

The average for Ca-concentration in the crop in 1980 was in the order: Ca-high > Ca-free > Ca-low fertilizer, but with considerable variation for the different iron compounds (Table 6). The P concentration followed this order for all harvests in 1979 (both rates of lime): Ca-free > Ca-low > Ca-high fertilizer (Table 3), and was distinctly higher for low liming than for high liming. However, because of the lower yield for Ca-free fertilizer combined with low liming, the total uptake of P was lowest for Ca-free fertilizer. The total uptake of P with low liming for all treatments in the harvest obtained at ear emergence was roughly equal to the rate of added P (147 mg per pot). Nearly the same order of P-concentration, highest for Ca-free and lowest for Ca-high, was also found in 1980 (Table 6).

The concentrations of Ca and P in the crops indicate that the chlorosis, combined with reduced yield, is more dependent upon a high concentration of P than a reduced uptake of Ca. Also, in earlier pot experiments with peat soil it was found that high supplements of P result in iron chlorosis (Sorteberg, A. 1963; Sorteberg, A. & G. Dev 1964). In this actual experiment attention should also be paid to the fact that the ratio of P/Fe in the crop by low liming in 1979 (Table 4) and by low iron supply in 1980 (Table 7) was in the order: Ca-free > Ca-low > Ca-high fertilizer. To a lesser extent the same order was found for the ratio P/Ca (Tables 4 and 7).

SUMMARY

In 1979 a pot experiment with sphagnum peat soil (pH about 5) resulted in iron chlorosis in oats, depending on the Ca-content in the fertilizers added, i.e. Ca-high, Ca-low and Ca-free. The corresponding degree of chlorosis was: None, light and heavy. At a pH of approximately 6 the oats were almost free of chlorosis even when the fertilizer was Ca-free.

In 1980 the effect of adding different Fe-compounds was examined with pH at about 5. When Fe-EDTHA chelate was added no chlorsis occured even when a Ca-free fertilizer was used. Fe-EDTA chelate with a 13% lower supply of Fe led to weak chlorosis. The lowest effect was with ferro sulphate and particularly with crushed Fe-rich slag. Without supplementary Fe-compounds considerable chlorosis occured, resulting in a marked reduction in yield.

The concentration of Fe in the crop in 1979 at low liming was highest for the Ca-high fertilizer at the first (of three) harvest times. In 1980 the Fe-concentration was highest for the Ca-high fertilizer both for the control and when Fe-compounds with a relatively low effect were added.

The concentrations of P in the crops for the different fertilizers were: Ca-free > Ca-low > Ca-high. The same order has also been found for the ratios P/Fe and P/Ca. With low liming and low iron supply to the oats the high level of chlo-

rosis was as a rule related to a high ratio of P/Fe and P/Ca respectively in the crop.

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A note on the use of a rising-plate meter to estimate herbage yield

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The design and use of a device for the non-destructive estimation of herbage production is described. The instrument, a rising- plate meter similar to that developed at the Hannah Research Institute, consists of two aluminium discs which move freely and vertically around a central, graduated rod. When placed on the ground the height of the lower disc is used as a measure of herbage height. This, however, is not the true herbage height, as it is influenced by sward condition, herbage mass and plant population density. The values obtained were found to be highly significantly correlated to herbage dry matter yields obtained from cutting 0.25 m^2 plots. The accuracy and the potential uses of this technique are discussed

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There are many occasions when either a non-destructive measurement of herbage production is required (e.g. during production trials), or as a simple alternative when a farmer wishes an estimate of pasture availability. As a result a number of techniques have been developed, varying from the IIFRO Sward Stick (Bircham, 1981), which simply measures herbage height, to the complex CSIRO electrical capacitance device (Vickery et al. 1980). This study investigated the use of a rising-plate meter similar to that originally developed at the Hannah Research Institute (Castle, 1976) for estimating herbage yields of both permanent pastures and sown pure ryegrass swards in southwest Norway.

MATERIALS AND METHODS

Device description

The measuring device consists of a central graduated rod and a movable section, weighing approximately 200 g, produced by holding two aluminium discs apart with three steel rods (Fig. 1). The central rod was produced from approximately 800 mm of rigid polythene tubing (dia. 30 mm) the ends of which were sealed with wooden blocks. Plastic tape was applied to one end to provide grip and an 80 mm steel pin inserted 10 mm from the other end to prevent the disc section from becoming disengaged during use. The two discs were made from sheet aluminium, diameters 100 and 300 mm respectively. A hole was cut in the centre of each disc large enough for the rod to pass through freely and the discs were joined using three thin steel rods

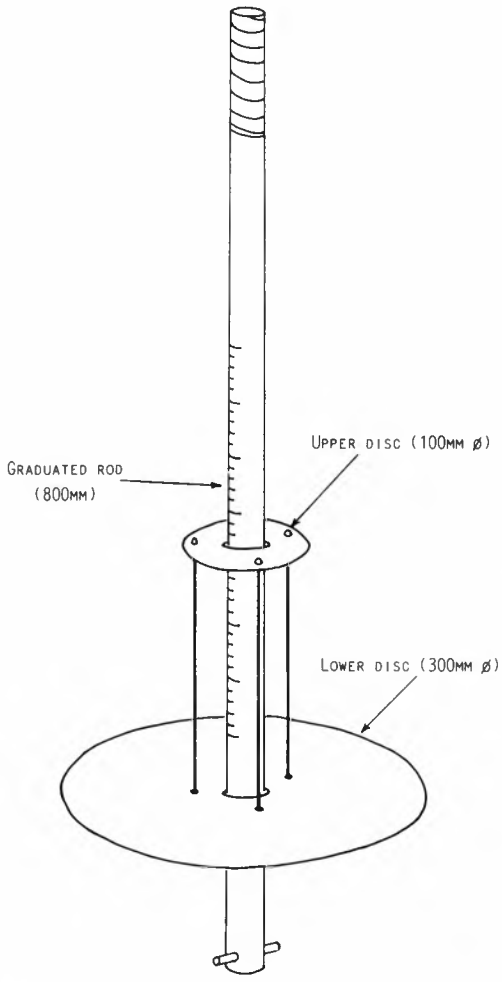

Figure 1. Diagram of the herbage measuring device

(200 mm in length) secured with small aluminium blocks and epoxy resin. Two small pieces of aluminium were then added to standardize the weight to 200 g. The device was assembled and a graduated scale (0 to 40 cm at 0.5 cm intervals), to give the height of the lower (larger) disc above ground level, engraved on the rod.

Measuring technique

The accuracy of the device in estimating production was assessed using two types of herbage; a pure Italian ryegrass (*Lolium multiflorum*, var. Meritra) sward sown in early April and a rotationally grazed permanent pasture in which the dominant grass species were *Phleum pratensis*, *Dactylis glomerata*, *Poa annua* and *Lolium perenne*. The selection of sampling sites varied depending on the herbage. Because of the uniformity of the ryegrass sward, sites at approximately 30 m intervals could be randomly selected, while a grid system giving preselected sites at 25 m intervals (to reduce the chance of inadvertent bias) was used for pasture estimation.

Herbage height was estimated using the following technique. With the disc section resting on the end pin, the base of the rod was placed on the ground and the disc section allowed to ride up the rod and the height read to the nearest 0.5 cm. It should be noted that as the weight of the disc section compressed the herbage to a certain extent, the use of the term «height» is not strictly correct but the measurement obtained is referred to as such throughout this paper. Four such measurements were taken within a 0.5 m quadrant and the mean value recorded. A description of the sampling site was also made and observations included sward condition, dominant species, ground condition and faecal contamination. A total of 19 estimates of pasture production (16 sites per estimate) were taken at three to four day intervals between weeks 20 and 29, while six ryegrass estimates (eight sites) were obtained (weeks 26 to 29). At all ryegrass sites and at three randomly selected pasture sites, the herbage in the quadrant was harvested to a height of approximately 1.0 cm using a Bosch AGS10 electric grass cutter and dried to constant weight, at 80°C, to obtain dry matter (DM) yields.

Statistical analysis

The data were entered into an Acer 1100 p.c. and validated by plotting stick height values against their respective

DM yields. Values which showed marked deviation were examined. The data were then subjected to analysis using SAS correlation and regression procedures (SAS, 1987) in order to obtain the relationship between height and DM yield. SAS procedures were also used to produce the cubic regressions and 95% confidence limits fitted to the height/DM yield plots (Figures 2 and 3).

RESULTS

Following the data validation process, four sets of values from the pasture assessment were excluded from further analysis. Although these values had been accurately recorded, they did not represent a true measure of herbage height/D.M. yield, as a result of long grass having been flattened (two occasions), contaminated with faeces or the ground being severely poached (one occasion each).

The relationships between herbage height and DM yield for the ryegrass and pasture swards are given in Tables 1 and 2 and Figures 2 and 3, respectively. Even though measured ryegrass sward heights varied from 5.5 to 31.0 cm, as the mean height increased during the growing season, good correlations were obtained between height and DM yield. When these values were pooled the correlation ($r = 0.895$) was found to be highly significant ($P>0.0001$), while the low level of significance obtained for the individual estimates is attributed to the small number of measurements taken. The regression analysis of the pooled height on yield data produced an R^2 value of 0.800 and coefficients which

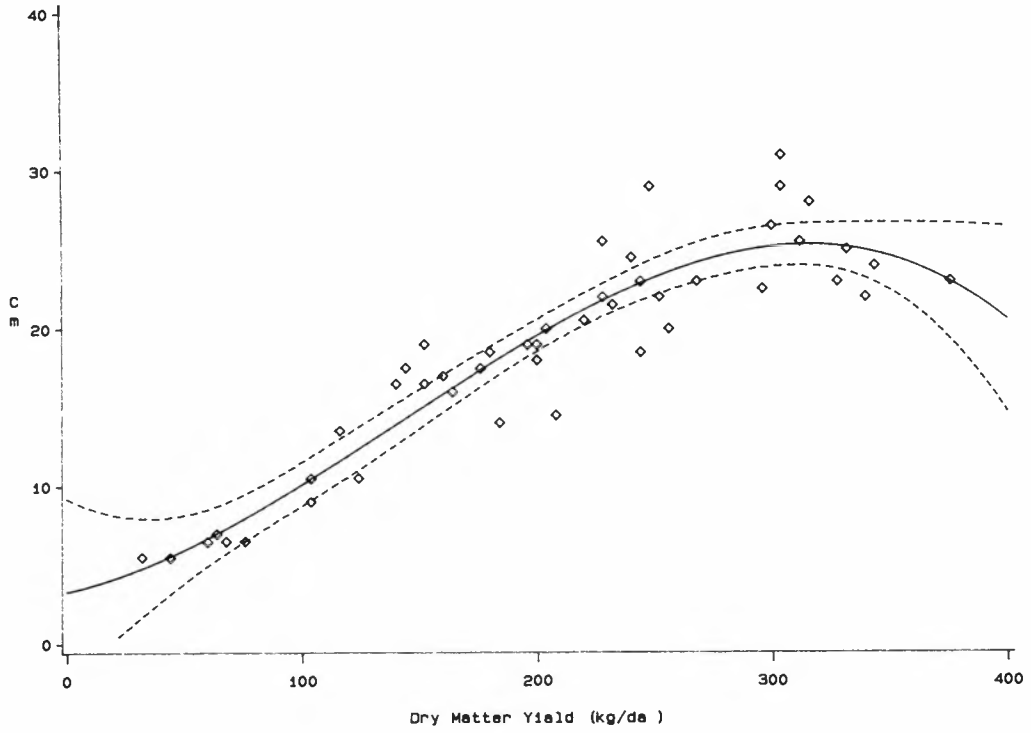

Figure 2. Relationship of measured ryegrass height (cm) to DM yield (kg/da). Fitted cubic regression (---) and 95% confidence limits (----)

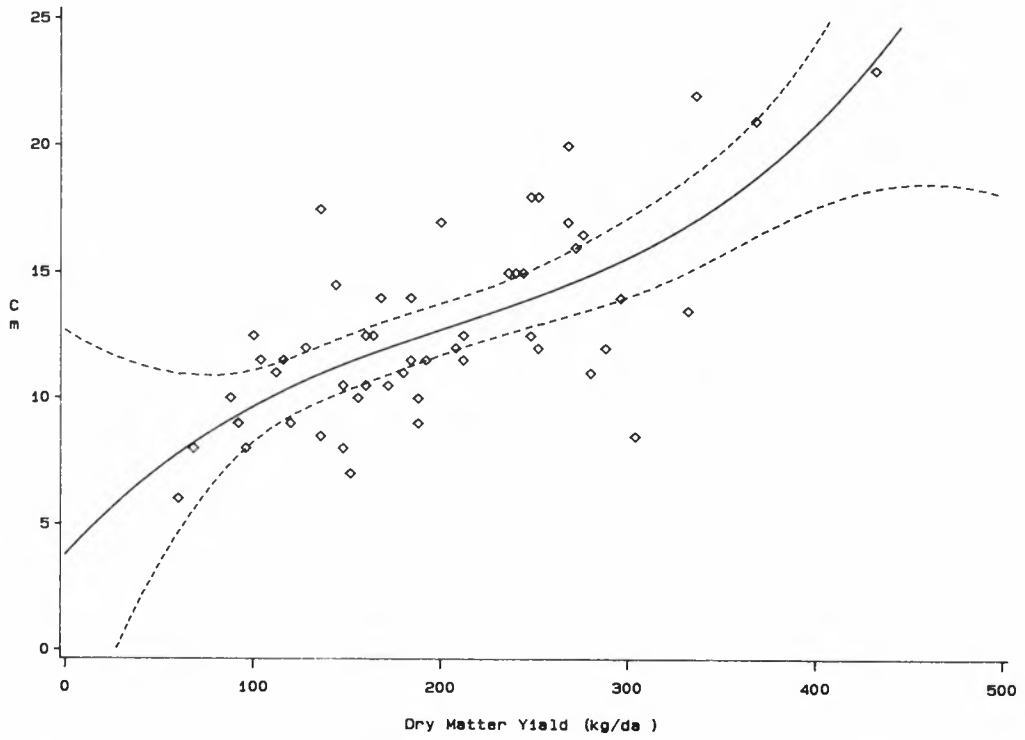

Figure 3. Relationship of measured pasture height (cm) to DM yield (kg/da). Fitted cubic regression ( ) and 95% confidence limits ( )

related height (cm) to DM yield (g m^{-2}) according to the formula:
DM yield = -12.6 + 11.77 height.

Sward heights of the grazed pasture obtained from 300 estimates ranged from 5.0 to 23.0 cm with a mean value of 11.41 cm. Sward condition varied to a greater extent than ryegrass (as seen by the higher SEM values) but significant correlations were obtained between height and DM yield in six of the nine analyses conducted. The pooled results,

Table 1. Correlation (r) and regression (R^2) relationships between ryegrass height (cm) and DM yield

Sample	n	Height Mean	Height Range	SE Mean	r	Sign.[1] (P >)	R^2
1	8	7.13	5.5 - 10.5	0.62	0.915	0.01	0.838
2	8	15.75	10.5 - 19.0	1.09	0.596	N.S.	0.355
3	8	17.88	16.0 - 22.5	1.35	0.879	0.01	0.773
4	8	22.50	18.0 - 25.0	0.73	0.677	N.S.	0.736
5	8	23.00	19.0 - 26.5	0.96	0.681	N.S.	0.464
6	7	25.86	20.5 - 31.0	1.65	0.799	0.05	0.639
Overall	47	18.53	5.5 - 31.0	0.98	0.895	0.0001	0.800

1. Significance

Table 2. Correlation (r) and regression (R^2) relationships between pasture height (cm) and DM yield

Pasture	n	Height		SE	r	Sign.[1]	R^2
		Mean	Range	Mean		(P >)	
1	5	11.10	5.0 - 14.0	1.62	0.800	N.S.	0.643
2	5	11.90	11.0 - 12.5	0.29	0.380	N.S.	0.145
3	6	14.58	7.0 - 18.0	1.58	0.927	0.01	0.859
4	6	11.67	8.0 - 17.0	1.29	0.847	0.05	0.718
5	5	16.00	11.0 - 22.0	2.09	0.882	0.05	0.777
6	6	15.42	8.0 - 21.0	2.00	0.939	0.01	0.881
7	5	13.40	8.5 - 23.0	2.64	0.995	0.001	0.990
8	3	11.00	8.0 - 14.5	[2]	[2]	[2]	[2]
9	6	10.08	9.0 - 11.5	0.40	0.425	N.S.	0.181
10	6	11.00	6.0 - 14.0	1.13	0.445	N.S.	0.198
Pooled	53	12.67	5.0 - 23.0	0.539	0.703	0.0001	0.494

1. Significance.
2. Too few values to give an accurate analysis

based on 53 estimates, were also found to be highly significantly correlated ($r = 0.703$, $P > 0.0001$). The R^2 value obtained from the pooled regression analysis was much lower (0.494) than that found with ryegrass, but included three sets of data where very low R^2 values had been found. Using the regression coefficients obtained, yield was found to be related to pasture height according to the formula: DM yield = 17.1 + 14.14 height.

DISCUSSION

The cubic regressions fitted to the two sets of data are in good agreement with the linear regressions (Figs. 2 and 3), with the 95% confidence limits demonstrating that the degree of variation found between height and yield was much greater in the pasture than in the ryegrass swards. They also both show a marked deviation at high and low height values. This is due in part to relatively few measurements having been taken and partly to the variation associated with the actual measurements themselves. Low height ryegrass values were associated with grass at an early growth stage and a low plant population density, while similar pasture values were generally found with a closely grazed established sward. In the grazed pasture study high height values were associated with mature, fibrous flowering grass growth, while high ryegrass height values were difficult to measure accurately, as the top of the grass plant had a tendency to bend over under its own weight or, especially so, after rain or heavy dew. This is probably the reason for the apparent increase in yield associated with a decrease in grass height (Fig. 3). From an analysis of the additional values obtained from the pasture study, an estimate could be made of the number of measurements required to provide an accurate assessment of DM yield. Height values obtained were randomly selected to provide 4, 8, 12 or 16 estimates, within sampling periods, of sward height. In addition, the values obtained from the height/yield study (three estimates per period) were included. These values, from 19 sampling periods, are presented in Table 3. The grid size is a measure of the distance between sampling points on a square grid pattern for a sampling area of 10,000 m^2. It can be seen that although a reliable mean height can be achieved with as few as ten observations 10,000

Table 3. Accuracy of sward height estimation

Observations per Estimate	Equivalent Grid Size (m)	Pasture Height Mean	SD	SEM
Pasture				
3	58	12.59	2.88	1.66
4	50	11.10	3.70	1.85
8	35	11.59	3.39	1.20
12	30	11.33	3.38	0.98
16	25	11.41	3.45	0.86
Ryegrass				
2	70	18.67	2.71	1.93
4	50	19.02	2.86	1.43
6	40	19.18	2.81	1.15
8	35	18.70	2.77	0.98

m^{-2}, the error associated with the estimate (SE mean) was high and decreased markedly as the sampling frequency increased. It would appear, therefore, that if the DM yield of pasture is to be estimated accurately, then a sampling interval of no less than 25 m should be used.

A similar process was followed with the ryegrass measurements, except that 2, 4, 6 and 8 measurements per estimate were used.

Little variation in the SD was found (Table 3), while SEM values decreased rapidly as the number of measurements per estimate increased. A ryegrass grid size of 35-40 m was found to have a similar SEM to that of a 25-30 m pasture grid and it would seem, therefore, that with such uniform swards a 35 m sampling interval is sufficient.

The technique has a number of applications apart from simply assessing grass production and thus, for instance, the number of days of grazing available. It could be used to estimate the area of grass which has to be cut to produce a given amount of silage. This would be of particular use when there is a delay between cutting and ensiling, such as when wilting is practised. The growth rate of cereal crops could be assessed, estimates of potential straw yields in crops prior to harvesting could be made as could, with appropriate factors, potential yields of brassica forage crops such as marrow-stem kale.

Although simple in construction, the device proved to be very robust, easy to use and produced rapid, highly repeatable results. Its limitations appear to be associated with the height and degree of maturity of the grass being measured, but within normal sward heights (i.e. 10 to 25 cm) the device can be used with a high degree of confidence to give a good, non-destructive estimate of DM yield.

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A lysimeter study on the nitrogen balance in soil

I. Fate of ^{15}N-labelled nitrate fertilizer applied to barley

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Calcium nitrate containing 9.80% ^{15}N was applied to barley over a 3-year period in a lysimeter experiment. The treatments, replicated three times, consisted of 80, 160, and 240 kg N ha^{-1} applied in spring to mineral soils from three sites. Fertilizer utilization differed only slightly for the three soils. N rates had little significant effect on the percentage recovery of applied N, whereas the corresponding values for straw showed an upward trend with increasing N rates. The recovery of fertilizer N in grain and straw for the 3-year period averaged 50 and 19%, respectively. Total N from fertilizer in the 0-20 cm topsoil layer determined at the end of the experiment was mainly unaffected by N rates, and varied from 14 to 18% for the three soils. Losses of fertilizer N through leaching were low, amounting to 1-2% at the higher N rate. Unaccounted-for losses of fertilizer N on the three soils were from 12 to 16%, and were probably caused by denitrification. For the 3-year period there was good agreement between the isotope method and the difference measurements of crop removal of N, although the difference method gave more varied results in individual years.

Key words: Barley, denitrification, ^{15}N, leaching of N, N-balance, N uptake.

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Maximizing the utilization of applied fertilizer N is of major agronomic interest. Whatever is not utilized by the crop may be stored in the soil, or may be lost in gaseous form or by leaching. By using a ^{15}N-labelled fertilizer it is possible to measure directly the crop recovery and soil accumulation of fertilizer N, and to estimate losses.

In a lysimeter experiment using ^{15}N, Kjellerup & Dam Kofoed (1983) found a 55% plant uptake of fertilizer N when barley was grown; the percentage crop uptake of fertilizer N slightly increased with increasing N. When applying 120 kg N ha^{-1}, Bergstrøm (1987) found a crop utilization of labelled N in barley of 63%.

In field experiments using labelled N, Craswell & Martin (1975) found a 53% plant uptake of fertilizer N with barley, and in winter wheat Olson et al. (1979) found a 57% utilization of 100 kg per ha applied N in spring. Considerably lower percentages of plant uptake were regi-

stered by Kowalenko & Cameron (1978) in a 3-year experiment with barley, and by Olson & Swallow (1984) in a 5-year experiment with winter wheat, the uptake of labelled N ranging from 27 to 34%.

Research figures referring to fertilizer N retained in the soil vary a great deal. In lysimeter experiments Chichester & Smith (1978) found 10-30% of labelled N remaining in the soil after a maize crop, whereas Thies et al. (1977) found 33-47% of fertilizer N in the soil following a barley crop. In a 5- year field experiment on winter wheat Olson & Swallow (1984) observed an average of about 50% of labelled fertilizer N in the soil, and in an 8-year field lysimeter with non-labelled fertilizer N Uhlen (1989) found 40-45% of immobilized N, the N retained being rather independent of crop and fertilizer rates.

Lysimeter data published by Kjellerup & Dam Kofoed (1983) showed leaching losses of labelled N of 5% when barley was grown. Usually 5-10% of fertilizer N is removed by leaching in ^{15}N lysimeter studies.

Unaccounted-for fertilizer N is usually presumed lost as a gaseous nitrogen. Referring to lysimeter experiments with ^{15}N, Thies et al. (1977), Chichester & Smith (1978), and Kjellerup & Dam Kofoed (1983) found unaccounted-for losses of 24-27%, 6-26%, and 16%, respectively. Field experiments show comparable results and indicate average figures of unaccounted-for losses of 10-30%.

Most of the experiments with ^{15}N comprise single-year fertilizer treatment. Continuous fertilizer applications could give different results. For this reason an experiment was conducted in order to determine the effects of annual applications of fertilizer N during a 3-year period.

MATERIALS AND METHODS

The lysimeters were made of PVC tubes 24 cm in diameter and 1 m deep with bottom plates of the same material. Each can was fitted with a drain pipe in the centre of the base. Water discharge was secured by a 5-cm layer of gravel placed at the bottom of each lysimeter. Soil samples from three sites were used in the experiment. The soil was removed from the field in three layers, at 0-20 cm, 20-50 cm, and 50-90 cm depths. After screening, the soil samples were placed in the lysimeters in three layers and packed to bring the soil level up to about 5 cm from the top. Some soil characteristics are given in Table 1. Soil samples 1 and 3 were of sandy loam while soil No. 2 was a silty loam. In accordance with

Table 1. Chemical and physical characteristics of the experimental soils

Soil No.	Depth cm	%					pH
		Clay	Silt	Sand	Tot. N	Org. C	
	0-20	10	29	61	0.20	2.7	6.6
	20-50	7	24	69	0.04	0.4	6.5
1	50-90	6	22	72	0.02	0.2	6.0
	0-20	25	57	18	0.28	3.0	6.1
	20-50	31	60	9	0.09	0.6	6.3
2	50-90	28	63	9	0.05	0.3	6.8
	0-20	8	20	72	0.22	2.6	7.2
	20-50	13	23	64	0.03	0.2	7.0
3	50-90	20	37	43	0.02	0.2	6.9

the FAO-UNESCO System, soil samples 1, 2, and 3 were classified as Dystric Cambisol, Dystric Gleysol and Gleyic Cambisol, respectively.

After an equally fertilized oat crop (120 kg N ha^{-1}) in all lysimeters in 1975, four N treatments were applied to spring barley in the three subseqent years 1976-78: 1. Control; 2. 80 kg N ha^{-1}; 3. 160 kg N ha^{-1}; 4. 240 kg N ha^{-1}. The nitrogen was applied as a solution of calcium nitrate labelled with 9.80% ^{15}N and mixed with the upper 10 cm of the soils. Rates of 60 kg P and 150 kg K per ha were applied annually as superphosphate and potassium sulphate, respectively, and mixed with the topsoil layer. Thirty-two seeds were broadcast in early May and later thinned to 24 plants. Each treatment was in three replicates.

Total rainfall between sowing and harvest in 1976, 1977, and 1978 was 78, 157, and 198 mm, respectively. The crop appeared to be affected by moisture stress both in 1976 and 1977, and therefore each lysimeter received extra irrigation, amounting to 100 mm in 1976 and 50 mm in 1977.

Sampling of lysimeter percolated water was restricted to the period from May through November, when the lysimeters were covered against frost. Hydrochloric acid was added to the water samples for preserving until they could be analysed. NO_3-N in the drainage water was determined by reducing the nitrate to ammonia using Devarda's reagent for distilling and titrating. The concentration of ^{15}N in the samples was determined using an emission spectrometer (Jasco N 150). Total N in grain and straw was determined by the Kjeldahl procedure and ^{15}N was analysed on the distillate. The soil samples were taken from the lysimeters at the end of the experiment; they were dried, sieved and analysed for total N by a Kjeldahl procedure modified to include NO_3-N with salicylic acid, followed by an analysis of isotope ratios.

Table 2. Yields of grain and straw of barley at different rates of fertilizer N application in three successive years

N applications kg ha^{-1} $year^{-1}$	Soil No.	Grain yield t dry matter ha^{-1}			Straw yield t dry matter ha^{-1}		
		1976	1977	1978	1976	1977	1978
0		1.40	3.25	1.48	1.86	3.35	2.05
80	1	4.39	5.23	6.01	5.28	6.01	7.34
160		4.79	5.42	7.82	6.14	6.66	9.50
240		4.49	5.01	8.16	6.20	7.40	10.94
LSD 5%		0.39	0.48	1.28	0.22	0.21	1.10
0		2.06	3.02	2.16	2.33	2.83	2.52
80	2	4.51	6.37	5.58	5.39	6.41	6.66
160		5.23	7.36	8.25	6.10	7.53	9.56
240		4.63	7.44	9.09	6.21	8.19	10.67
LSD 5%		0.77	0.31	0.55	0.27	0.27	0.68
0		1.47	2.62	2.63	2.48	2.72	3.15
80		3.83	4.99	6.36	5.05	5.56	7.72
160	3	4.17	5.44	8.35	5.77	6.80	9.71
240		3.44	5.08	8.42	6.02	7.63	10.48
LSD 5%		0.47	0.36	0.32	0.32	0.36	0.28

RESULTS

Grain and straw yields

Plant growth in N-fertilized lysimeters was retarded because of water shortage in 1976, although extra water up to about 100 mm was applied to each lysimeter. In the second year plant growth was somewhat hampered by periodical drought in soil samples 1 and 3, whereas the plants in soil No. 2 seemed to be unaffected, probably because of the greater water capacity. In the third year, when shortage of water was not a limiting factor for growth, the yields of the fertilized lysimeters increased to a considerably higher level compared to the preceding years (Table 2).

There were significant grain and straw yield increases from N in the three soils in all years. Application of 160 kg N ha^{-1} generally gave a significantly higher grain yield than 80 kg, whereas application of 240 kg N depressed the grain yield compared to 160 kg in all three soils in 1976 and in two soils in 1977. Straw yields generally increased significantly with increasing N applications up to the 240 kg rate.

N concentrations in the crop

The two higher N rates in 1976 and 1977 resulted in a marked increase in the N concentrations of grain and straw, as shown in Fig. 1. The results must be seen in relation to the low yield increases or yield depressions at the two higher N application rates. In 1978, when water shortage was not a limiting factor for growth, high yield increases at the lower N rate resulted in decreased N concentrations in grain and straw (dilution effect), followed by a moderate increase in N concentration at the higher N rates (Fig. 1).

The N concentrations of the crop varied from soil to soil, the variations being mainly related to yield differences. Thus in 1976 and 1977 the higher yield in soil No. 2 resulted in lower N concentrations compared to the other soils.

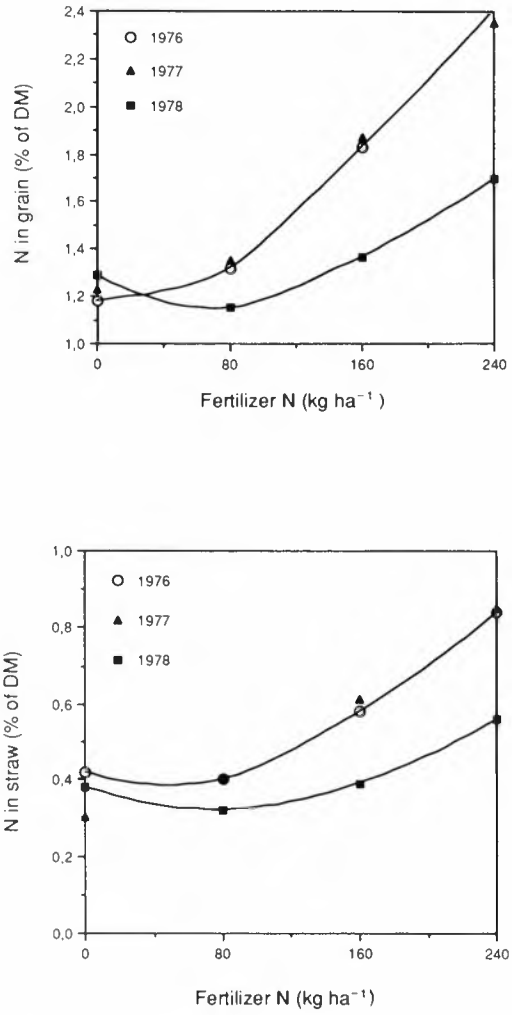

Fig. 1. N concentrations in grain and straw as affected by N rates in different years

Fertilizer N uptake

Isotope recovery fractions expressed as percentages of the amounts applied are given in Table 3 on a yearly basis for the three N rates in the separate soils. Fertilizer N recovered in the grain crop was considerably higher in the second and third years compared to the first year. Averaged over soils and N rates, the first year recovery of applied N amounted to 42%, compared with 55 and

Table 3. Isotope recoveries at different rates of N fertilizer applied to barley

N applications kg ha^{-1} year^{-1}	Soil No.	^{15}N recoveries, % Grain 1976	Grain 1977	Grain 1978	Straw 1976	Straw 1977	Straw 1978
80		43.7	55.0	47.6	15.6	17.6	14.7
160	1	41.8	55.6	51.6	15.7	20.1	16.4
240		43.2	46.7	55.0	17.6	25.2	19.9
LSD 5%		8.5	7.0	6.5	3.3	2.1	2.1
80		40.8	62.8	47.0	15.3	17.3	16.6
160	2	45.8	61.1	54.8	16.7	19.0	17.9
240		41.1	59.9	52.5	17.4	20.3	22.0
LSD 5%		5.8	4.7	2.9	4.5	2.8	1.9
80		43.3	53.9	52.0	16.6	17.4	16.7
160	3	43.8	56.3	55.6	18.0	21.1	18.7
240		36.8	49.1	54.4	22.1	24.2	20.7
LSD 5%		7.0	3.2	5.6	4.3	3.3	1.6

53% in the second and third years, respectively. Fertilizer N uptake in straw varied less from year to year, amounting to 18, 21 and 19% of that applied in the first, second and third years, respectively.

Plant uptake values in the second and third years reflect the effects of both yearly application of fertilizer and residual fertilizer N from previous years. The differences in uptake percentages were, however, mainly due to variations in the growing conditions, especially variations in water supply.

The percentage of applied fertilizer N recovered in grain crop on the three soils differed only slightly, apart from 1977 when the uptake values on soil No. 2 were significantly higher compared to the other two soils. There were also small differences in uptake percentages of applied N in straw in the three soils. In the main, fertilizer N rates had no significant effect on the percentage N recovered in grain, whereas the percentage N recovered in straw showed an upward trend with increasing N rates.

Averaged over soils and N rates, fertilizer N recovered in the total yield was 60% of that applied in the first year, and 76 and 72% of that applied in the second and third years, respectively. Uptake values were not significantly affected by N rates in the first year, whereas in the two successive years the percentage of fertilizer N uptake was higher at the 160 and 240 kg N rates compared with the 80 kg rate, which may reflect a residual effect at the two higher N rates.

Fertilizer nitrogen taken up by a crop can be estimated as the difference between N removal by fertilized and unfertilized plots (difference method) and by the isotope dilution method (direct method). Table 4 shows the values for both methods on the average of the three soils for the 3-year period. On the whole there was good agreement between the two methods. The difference method gave somewhat higher values for total yield removal of fertilizer N at the 80 and 160 kg N rates compared to the direct method, whereas there was an opposite trend at the 240 kg rate. The results for

Table 4. Crop removal of fertilizer N as measured by ^{15}N and difference methods. Average values for the 3-year period

N-applications kg ha^{-1} year^{-1}	Fertilizer N removed by crop, kg ha^{-1}	
	^{15}N method	Difference method
80	52.8 + 2.9*	56.8 + 6.8
160	112.0 + 5.8	114.4 + 9.7
240	167.5 + 5.3	162.9 + 8.1

* Standard deviation

separate years showed consistently higher values for the difference method on all soils at the 80 kg N rate, whereas there was an opposite trend at the 240 kg N rate. At the 160 kg N rate the two methods gave varied results, the average value being a little higher for the difference method (Table 4). As shown by the standard deviation values in Table 4, the difference method resulted in greater variability for fertilizer N removal by the crop.

Non-fertilizer N uptake

By using labelled fertilizer it was possible to calculate the amounts of soil N uptake by the crop. Values for grain and straw uptake on the three soils in different years are given in Table 5. Effects of fertilizer on utilization of soil N varied from year to year. In the first year the 80 and 160 kg N rates resulted in an upward trend of soil N uptake by grain, whereas the 240 kg N rate caused a marked lowering of uptake in all soils. In the second year N uptake by grain was

Table 5. Amounts of non-fertilizer N in grain and straw at different fertilizer rates

N applications kg ha^{-1} year^{-1}	Soil No.	N uptake, kg ha^{-1}					
		Grain			Straw		
		1976	1977	1978	1976	1977	1978
0		20.0	45.5	21.8	10.4	12.7	11.3
80		28.1	35.8	39.1	10.7	11.8	12.2
160	1	26.9	28.5	39.1	13.7	11.7	13.2
240		12.5	20.2	31.6	11.8	15.2	13.4
LSD 5%		8.9	4.7	12.3	2.3	4.7	2.7
0		25.7	40.0	30.3	9.4	8.4	9.9
80		31.6	39.1	34.1	10.7	11.5	10.8
160	2	26.8	38.7	37.8	9.3	13.8	12.5
240		15.4	32.6	34.5	10.0	13.3	15.1
LSD 5%		10.4	5.0	3.0	2.6	2.0	1.3
0		18.0	30.3	35.2	10.0	8.3	9.4
80		22.9	32.0	35.2	8.3	11.4	11.7
160	3	20.6	24.6	30.3	8.8	14.9	11.4
240		10.8	21.6	27.0	8.3	14.1	12.3
LSD 5%		6.7	8.8	5.1	3.3	3.7	1.4

mostly decreased by N applications, especially at the 240 kg N rate. The results in the third year showed that N applications markedly increased soil N utilization by grain on soil samples 1 and 2, and decreaced it on soil No. 3.

Soil N uptake by straw yield varied less from year to year compared to grain uptake, but straw uptake was also affected by fertilizer N application. As shown in Table 5, there were several cases of an upward trend in soil N uptake with increasing N applications. This partly modified the differences in non-fertilizer N utilized at various N rates by the whole crop compared to the grain values.

Fertilizer N leached

Because the lysimeters were covered in winter there was reduced loss of N. Drainage water from the fertilized lysimeters varied from almost zero to about 180 mm. Amounts of N lost by leaching were highest in 1976, mainly as a result of heavy rains in the autumn, but probably also as a result of higher residual N in soils caused by a dry growing season (Table 6).

The amounts of N leached were generally lower in soil No. 2 compared to the other two soils, and this is explained by the different physical characteristics. In the first year fertilizer N leached at the two lower N rates was about 0.5% of that applied to soil No. 2, and from 0.7 to 1.3% of that applied to soil samples 1 and 3. At the 240 kg N rate fertilizer N losses were in the range of 2.5-3% of that applied to all soils.

Fertilizer N losses were extremely low in soil No. 2 in the second and third years. In soil No. 1 fertilizer N leached was in the range 0.5-1.0% in the second year, and 1.0-1.2% in the third year. Corresponding figures for soil No. 3 were 0.9-1.4% in the second year and 1.1-2.2% in the third year.

Table 6. Yearly leaching of fertilizer and non-fertilizer N at different fertilizer rates

N applications kg ha $^{-1}$ year $^{-1}$	Soil No.	Leaching, kg N ha $^{-1}$ Fertilizer N 1976	1977	1978	Non-fertilizer N 1976	1977	1978
0		-	-	-	34.3	12.2	20.5
80		0.5	0.4	0.8	20.1	7.5	10.9
160	1	1.9	0.9	1.6	22.5	6.4	10.2
240		6.7	2.4	2.9	28.6	7.3	10.9
LSD 5%		3.0	0.3	0.3	9.3	4.6	5.4
0		-	-	-	10.9	0.8	5.1
80		0.4	0.0	0.2	14.7	0.4	2.4
160	2	1.0	0.0	0.3	17.6	0.2	1.4
240		7.2	0.1	0.2	22.4	0.3	0.6
LSD 5%		1.6	0.1	0.2	3.6	0.6	2.4
0		-	-	-	17.4	7.6	9.3
80		1.0	0.7	0.9	25.6	7.8	9.7
160	3	2.1	1.4	2.0	27.4	7.1	9.4
240		6.1	3.4	5.3	32.4	7.8	12.6
LSD 5%		1.4	0.5	0.4	5.8	1.8	1.8

Non-fertilizer N leached
Leaching losses of non-fertilizer N were considerably greater than the losses of fertilizer N, especially in the first year (Table 6). Like fertilizer N, leaching of non-fertilizer N was lower in soil No. 2 compared to the other two soils. In all soils there was a consistent increase in non-fertilizer N losses with increasing N rates in the first year, mainly as a result of an increase in N concentration of the leachate. In the second year there were no significant treatment differences for non-fertilizer N losses, whereas in the third year N applications resulted in reduced non-fertilizer N losses in two of the soils. In both the second and third years drainage water decreased with increasing N applications, reflecting the higher water use by plants in the fertilized lysimeters, and this may at least partly explain the reduced non-fertilizer N losses in fertilized lysimeters. The concentration of non-fertilizer N in the leachate generally increased with increasing N rates in both the second and third years.

Fertilizer N in soil
The amounts of total N from fertilizer in the top 20 cm of the lysimeters were measured at the end of the experiment. Subsoil samples were not analysed for residual fertilizer N owing to too low total N concentrations. Ammonium- and nitrate-N determined in representative subsoil samples showed low values that were not affected by fertilizer treatments. Comparable results were obtained for the 0-20 cm layer. Most of the residual fertilizer N shown in Table 7 was therefore assumed to be immobilized in organic form in the soil.

The residual fertilizer N in the 0-20 cm layer was approximately proportional to the amounts of fertilizer N applied to each soil sample. The residual values did not vary much from soil to soil, amounting to 14% of that applied to soil No. 3, and to 17 and 18% to soil samples 1 and 2, respectively.

Nitrogen balance
The recovery of labelled fertilizer in crop plus that remaining in the soils, calculated for the 3-year period and averaged over the three N rates, was 84, 88 and 83% for soil samples 1, 2 and 3, respectively. Leaching losses of fertilizer N were insignificant on all soils. As N was applied as nitrate, unaccounted-for losses were assumed to be due to denitrification. Amounts of unaccounted-for losses were determined by difference and included accumulated errors of sampling, sample preparation and analyses. In this experiment the values for unaccounted-for losses also included any fertilizer N possibly remaining in the subsoil.

Because of the similarity in the results for the three soils the N balance for the 3-year period is given as the average figures for the three soils (Table 8). The percentage removal of applied N by the crop was somewhat lower at the 80 kg N rate compared to the higher N rates, whereas N remaining in the soil was about the same for all N rates. In spite of

Table 7. Fertilizer N remaining in the soil (0-20 cm) after three years of treatment

Soil No.	Fertilizer N found kg N ha^{-1} 80 kg N	160 kg N	240 kg N	LSD 5%	% of applied N 80 kg N	160 kg N	240 kg N
1	38.8	86.3	113.3	12.5	16.2	18.0	15.7
2	43.3	85.3	129.2	19.6	18.0	17.8	17.9
3	33.7	66.0	95.4	12.9	14.0	13.7	13.2

Table 8. Nitrogen balance after three years of annual nitrogen applications. Average values for three soils, kg N ha^{-1}

Fate of fertilizer N	Fertilizer N applied, kg ha^{-1} $year^{-1}$ 80	160	240
Removed by grain	119.0	248.7	350.9
Removed by straw	39.4	87.3	151.5
Leaching	1.6	3.8	11.4
Present in total soil N (0-20 cm)	38.6	79.2	112.6
Unaccounted-for losses	41.4	61.0	93.6

higher leaching values at the higher N rates the calculated unaccounted-for loss of fertilizer N was unexpectedly higher at the 80 kg rate compared to the higher N rates. The unaccounted-for losses amounted to 17, 13 and 13% at the 80, 160 and 240 kg N rates, respectively. Similar results for the percentage removal of applied N by the crop, residual N in soil and unaccounted-for losses in relation to N rates were obtained in a lysimeter study by Kjellerup & Dam Kofoed (1983).

DISCUSSION

The crop utilization of fertilizer N differed from year to year, partly depending on variations in the water supply. Calculated for the 3-year period, fertilizer N uptake by the crop was approximately the same on the three soils (68-71%). For the N rates, somewhat higher uptake values were obtained at the 160 and 240 kg rates compared with the 80 kg rate. This was mainly a result of the upward trend in straw N uptake with increasing N rates. The crop utilization of fertilizer N for the 3-year period was fairly high. This was mainly a result of high yields and low leaching losses.

The residual effects of fertilizer N in the second and third years are difficult to assess. Reduced plant growth caused by periods of drought combined with low leaching losses in the first and second years would imply significant residual effects of N fertilizer at the higher N rates. A residual effect was indicated by the greater uptake percentages of fertilizer N in grain at the two higher N rates compared with the 80 kg rate in the third year. The significant increase in N fertilizer uptake percentages of straw with increasing N rates in the second and third years in most soils also indicates residual effects of N.

The difference method is generally assumed to give higher recoveries than the ^{15}N method (Jansson & Persson 1982). The discrepancy has been ascribed to (1) increased mineralization in fertilized plots, (2) mineralization-immobilization turnover, and (3) increased root development in fertilized plots (Harmsen & Moraghan 1988). In this experiment the two methods gave about the same result; the difference method showed some higher values at the two lower N rates, whereas the opposite was the case at the higher rate.

The amounts of fertilizer N remaining in soils at the end of the experiment, corresponding to 13-18%, were in the lower range of what has been found by other workers. A factor contributing to the results in this experiment was probably, in addition to high yields, the use of nitrate as the N form.

The low leaching values for fertilizer N indicate that fertilizer N in the soil was mainly retained in the top layer, and that only small amounts were left in the subsoil. The unaccounted-for fertilizer N

was therefore assumed to be lost by denitrification. These losses were also within the range of values found by other workers.

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Experiments with clones of cocksfoot (*Dactylis glomerata* L.)

Interaction between selected clones and nitrogen fertilizer

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Genotypes from high-, median-, and low-yielding groups of clones from a population of *Dactylis glomerata* were investigated for their response to different rates and sources of nitrogen. The two N- sources, ammonium and nitrate, do not produce significantly different yields, but ammonium gives a higher N-concentration in the plants and produces more tillers than nitrate. The high-yielding genotypes show the strongest response to rates of nitrogen. For several traits there is significant interaction between genotypes and nitrogen treatments. Only in a few cases, however, do the interactions lead to a change in the rank of groups. For most traits and treatments the groups were ranked as for yield. Findings indicate that some genotypes respond in a «nitrate nitrophilous» way, others in an «ammonium nitrophilous» way.

Key words: cocksfoot, Dactylis glomerata, genotype - environment interaction, nitrogen response

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In the breeding of grasses, many characters are evaluated under spaced plant conditions, when the goal is really an improved phenotype under sward conditions; the two environments are very different in many respects. In addition, a variety that will perform well under various management and climatic conditions is usually preferred. This underlines the importance in selection of assessing the magnitude of genotype-environment interactions, or environmental response, as well as the main effects of genotypes. Although this problem has been recognized by plant breeders for many years, it is only in the last two decades or so that it has been possible to deal positively with this type of research.

Interest in genotype-environment interactions was aroused in recent years by the rediscovery of the application of linear regression methods for describing the interaction process. The regression methods are useful whether the approach to the problem is mainly statistical (Yates & Cochran 1938, Vik 1925, Finlay & Wilkinson 1963, Eberhardt & Russell 1966), or is more along the lines of biometry and genetics (Mather & Jones

1958, Bucio-Alanis 1966, Bucio-Alanis & Hill 1966). The technique which has been used in numerous works is statistically biased in some of its applications, as pointed out by several workers and as reviewed by Hill (1975). However, the actual bias has been found to be small, provided that a sufficiently large number of environments and genotypes are used.

Genotype-environment interactions have been investigated for complex characters like grain yield in cereals or dry matter production in perennial grasses. The response to environmental changes or differences has been shown to be inherited, and both a predictable linear response and a non-predictable scatter around the regression line appear to be genetically controlled (Bains 1976).

One assumption in the applied regression technique implies that the environmental variability should be defined in terms of variation in environmental means. The environment, defined as its mean «performance» over a range of genotypes, is usually a highly complex item. From an agronomic or economic point of view, single environmental components are often of interest. Similar regression techniques and definitions of environment as with complex environmental differences may of course be used, but they require simultaneous records of physical or economical input of the environmental variable.

Rate of fertilizer, particularly nitrogen (N), is an environmental component of special interest in agriculture. From comparative trials of species and varieties researchers have long recognized the interaction between genotypes and rate of N-fertilizer (Vik, l.c.; Vose & Breese 1964).

Studies of genetic variation in enzyme activities have become a field of increasing interest to genetics and plant breeding too, (Nelson et al. 1975); of interest in connection with N-assimilation is a genetic variation found in the activity of nitrate reductase in several *Gramineae* spp. (Bowerman & Goodman 1971, Goodman et al. 1974, Eck & Hageman 1974, Eck et al. 1975). A positive correlation between yield and activity of nitrate reductase was found among some varieties of perennial ryegrass by Bowerman & Goodman, l.c.

Increased rates of N in the nutrient solution usually increase the activity of nitrate reductase; a similar effect of N-fertilizer in the field has been demonstrated (Bar-Akiva et al. 1970). With increased rates of N-fertilizer, there is a higher yield and a better quality of grass, but when N is supplied in nitrate form, there is also the risk of unwanted nitrate accumulation and the formation of toxic levels of nitrite in the rumen of cattle or sheep. High levels of nitrate in the nutrient solution of plants may also produce an imbalance between activities of nitrate reductase and nitrite reductase (Goodman et al. 1974).

The objective of this study is to examine the possible relationship between differences in yield and response to applied N among selected phenotypes within a population of cocksfoot.

MATERIALS AND METHODS

A. Experimental procedures

Prior to this study the variability in yield among 200 randomly selected cocksfoot clones from the Norwegian population «Løken», had been assessed over two consecutive years in a spaced plant nursery, where N was supplied in nitrate form throughout. In spring, and after the first and second cuts respectively, the rates were 96, 93, and 47 kg N/ha in the first year, and 96, 0, and 93 kg N/ha in the second year (Honne 1979).

From the frequency distribution of the mean annual yield of the 200 clones, two were selected from the group with the highest yield, two from around the median of the distribution, and two from the group with the lowest yield. Single tiller ramets from each clone were rinsed in tap water and planted in 12 plastic

boxes (46 x 30 x 9 cm^3), each filled with 17 kg sand. Each box contained two ramets in a «plot» from each clone, and clones were randomly distributed within boxes. Six boxes were used per replicate.

The sand was free of organic matter (had been heated to glowing), and chemical analyses showed the following contents of plant nutrients: phosphorus 1.3 as P-AL, potassium 0.8 as K-AL, and magnesium 0.8 as Mg-AL. At planting, 3 litres of a nutrient solution was added to each box; the solution was composed in accordance with Hewitt (1966, Table 40), except for the N. Six N-treatments were introduced (3 rates and 2 sources): 4 mM, 12 mM, and 20 mM of N per litre nutrient solution, added as nitrate or ammonium. During the establishing period, all the plants were given 4 mM N/litre as ammonium. During the experiment, nutrients, including N, were added every second to third day; half a litre per box at a time. The sand in each box to be treated with ammonium was mixed with 30 grams of ground limestone at planting.

The plants were grown in a glasshouse at a temperature of 12-14°C and a photoperiod of 16 h (natural daylength was extended by approx. 6000 lux from white fluorescent tubes). The plants were allowed to become established and were then trimmed to a uniform height at the onset of the experiment. After 73 days the plants were cut to uniform height; fresh weight (FW) and dry weight (DW) were recorded in grams per plot and the material was analysed for Kjeldahl-N and nitrate-N. The amount of reduced N has been calculated as Kjeldahl-N less nitrate-N. Three weeks after the first cut a second cut was taken, but this time only the fresh weights were recorded.

B. Analyses of data

The design of the experiment was such that the variance of main effects of N-sources and that of the interaction between rates and sources formed components of the variance among boxes, while the variance of clones and that of interaction between clones and nitrogen treatments, formed components of the variance within boxes. In the statistical model the effects of source and rates of N were treated as fixed variables. The clone effect was split into two parts: one fixed effect due to the group from which the clone was selected, and one random effect due to variation within groups. That is to say the clones are considered random representatives of the selected groups which are to be compared.

The statistical model for an observation is:

$$Y_{ijklm} = \mu + \alpha^{A}_{i} + \alpha^{B}_{j} + \alpha^{C}_{k} + D^{C}_{kl} + \alpha^{AB}_{ij} + \alpha^{AC}_{ik} + D^{AC}_{ikl} + \alpha^{BC}_{jk} + D^{BC}_{jkl} + \alpha^{ABC}_{ijk} + D^{ABC}_{ijkl} + E_{ijm} + F_{ijklm}$$

where:

μ: overall mean

α^{A}_{i} : effect of N-source i, fixed effect; i = 1, ..., a

α^{B}_{j} : effect of N-rate j, fixed effect; j = 1, ..., b

α^{C}_{k} : effect of group k of clones, fixed effect; k = 1, ..., c

D^{C}_{kl} : effect of clone l within group k, random effect; l = 1, ..., d

α^{AB}_{ij} : effect of interaction between N-source i and rate j, fixed effect

α^{AC}_{ik} : effect of interation between N-source i and group k of clones, fixed effect

D^{AC}_{ikl} : effect of interaction between N-source i and clone l within group k, random effect

α^{BC}_{jk} : effect of interaction between N-rate j and group k of clones, fixed effect

D^{BC}_{jkl} : effect of interaction between N-rate j and clone l within group k, random effect

α^{ABC}_{jik} : effect of interaction between N-source i, N-rate j and group k of clones, fixed effect

D^{ABC}_{ijkl} : effect of interaction between N-source i, N-rate j and clone l within group k, random effect

E_{ijm} : effect of box m for the combination of N-source i and N-rate j, random effect; m = 1, ..., e

F_{ijklm} : effect of random error

The expected mean squares of the analyses of variance of this model are given in Table 1. The author is indebted to prof. dr. E. Spjøtvoll of the Agricultural University of Norway for formulating the model and for working out the expectations. As can be seen from Table 1, the significance of all the components can be tested, but not all by a ratio of two mean squares. In some cases approximate F-tests have to be constructed, according to Snedecor & Cochran (1967). Where linear regressions were calculated for investigating interactions, standard procedures have been used (see for instance Snedector & Cochran, l.c.; Draper & Smith 1966).

RESULTS

A. Nitrogen treatments, main effects, and interactions

The two N-sources did not produce significantly different yields (measured in grams per plot) either of fresh weight (FW) or of dry weight (DW), (Tables 2 and 3). However, the two higher N-rates (12 mM and 20 mM) resulted in increased yields as compared with 4 mM.

Ammonium-N gave a significantly higher number of tillers than nitrate-N, and 12 and 20 mM N gave significantly more tillers than 4 mM N. The decrease from 12 to 20 mM N was non-significant (Tables 2 and 3).

Because the higher number of tillers with ammonium-N did not result in a significantly higher yield, the weight of individual tillers or yield per 10 harvested tillers was lower with ammonium-N than with nitrate-N ($p < .01$). Nitrogen rates had no significant effect on tiller weight (Tables 2 and 3).

The concentrations of total N and reduced N were higher with ammonium-N than with nitrate-N ($p < .01$, Table 4).

Table 1. Scheme for analysis of variance with expectations for the mean squares.

Source of variation	df	Exp. mean square
N-source (N_s)	(a-1)	$\sigma^2 + cd\,\sigma^2_E + e\,\sigma^2_{ABC} + be\,\sigma^2_{AC} + \frac{bcde}{(a-1)} \sum_i (\alpha^A_i)^2$
N-rate (N_r)	(b-1)	$\sigma^2 + cd\,\sigma^2_E + e\,\sigma^2_{ABC} + ae\,\sigma^2_{BC} + \frac{acde}{(b-1)} \sum_j (\alpha^B_j)^2$
$N_s \times N_r$	(a-1)(b-1)	$\sigma^2 + cd\,\sigma^2_E + e\,\sigma^2_{ABC} + \frac{cde}{(a-1)(b-1)} \sum_i \sum_j (\alpha^{AB}_{ij})^2$
Residual 1 (from between boxes)	ab(e-1)	$\sigma^2 + cd\,\sigma^2_E$
Between groups of clones (G_a)	(c-1)	$\sigma^2 + e\,\sigma^2_{ABC} + ae\,\sigma^2_{BC} + be\,\sigma^2_{AC} + abe\,\sigma^2_C + \frac{abde}{(c-1)} \sum_k (\alpha^C_k)$
Within groups of clones (G_w)	c(d-1)	$\sigma^2 + e\,\sigma^2_{ABC} + ae\,\sigma^2_{BC} + be\,\sigma^2_{AC} + abe\,\sigma^2_C$
$G_a \times N_s$	(a-1)(c-1)	$\sigma^2 + e\,\sigma^2_{ABC} + be\,\sigma^2_{AC} + \frac{bde}{(a-1)(c-1)} \sum_i \sum_k (\alpha^{AC}_{ik})^2$
$G_w \times N_s$	c(a-1)(d-1)	$\sigma^2 + e\,\sigma^2_{ABC} + be\,\sigma^2_{AC}$
$G_a \times N_a$	(b-1)(c-1)	$\sigma^2 + e\,\sigma^2_{ABC} + ae\,\sigma^2_{BC} + \frac{ade}{(b-1)(c-1)} \sum_j \sum_k (\alpha^{BC}_{jk})^2$
$G_w \times N_a$	c(b-1)(d-1)	$\sigma^2 + e\,\sigma^2_{ABC} + ae\,\sigma^2_{BC}$
$G_a \times N_s \times N_r$	(a-1)(b-1)(c-1)	$\sigma^2 + e\,\sigma^2_{ABC} + \frac{de}{(a-1)(b-1)(c-1)} \sum_i \sum_j \sum_k (\alpha^{ABC}_{ijk})^2$
$G_w \times N_s \times N_r$	c(a-1)(b-1)(d-1)	$\sigma^2 + e\,\sigma^2_{ABC}$
Residual 2 (from within boxes)	ab(cd-1)(e-1)	σ^2

Table 2. Overall means and means for two sources, N_s, and three rates, N_r, of nitrogen

Character	Overall	N_s		N_r		
		NH_4^+	NO_3^-	4mM	12mM	20mM
FW 1. cut, g/plot	12.59	12.99	12.19	8.81	14.89	14.11
DW 1. cut, g/plot	3.26	3.34	3.18	2.49	3.78	3.52
Number of tillers/plot	12.4	14.4	10.4	9.4	14.4	13.5
DW 1. cut, g/10 tillers	2.65	2.31	2.99	2.74	2.61	2.61
Kjeldahl-N, g N/100g D.M.	2.75	3.05	2.45	1.65	2.91	3.70
Nitrate-N, mg N/100g D.M.	163.-	77.-	248.-	59.-	195.-	233.-
Reduced N, g N/100g D.M.	2.59	2.98	2.21	1.59	2.72	3.46
Total reduced N, mg/plot	90.0	106.9	73.1	39.1	107.6	123.4
FW 2. cut, g/plot	4.07	4.34	3.80	3.60	5.17	3.44

Table 3. Mean squares from analyses of variance for four characters. The appropriate variance ratios for tests of significance for each of the components can be found in Table 1

Item	DF	FW 1.cut g/plot	DW 1.cut g/plot	Number of tillers/plot	DW per 10 tillers
N-source (N_s)	1	11.5280	0.4688	284.01**	8.3641**
N-rate (N_r)	2	260.9065**	11.2894**	173.10**	0.1288
$N_s \times N_r$	2	1.1107	0.3620	23.18	0.3028
Residual 1	6	3.4749	0.4861	11.10	0.4940
Between groups (G_a)	2	571.5474*	32.7284	219.43**	2.4316
Within groups (G_w)	3	245.2929	10.7148	3.57	4.5411*
$G_a \times N_s$	2	37.6479	2.0856	8.19	0.7073
$G_w \times N_s$	3	53.1508*	3.6402*	39.51	0.6805
$G_a \times N_r$	4	49.0435*	2.5174*	38.68	0.2985 (1
$G_w \times N_r$	6	22.3931	1.0081 (1	8.49	0.2420 (1
$G_a \times N_s \times N_r$	4	48.1950*	2.8818*	28.72	0.2089 (1
$G_w \times N_s \times N_r$	6	22.3899	1.1523 (1	23.43	0.1889 (1
Residual 2	30	16.5480	0.9384	11.50	0.2973
Pooled error (DF)			0.9789 (42)		0.2709 (50)

1) Included in pooled error
* $p < .05$
** $p < .01$

Consequently, as DW of yield did not differ significantly between the two N-sources, the amount of reduced N harvested per plot was higher with ammonium-N than with nitrate-N ($p < .01$, Tables 2 and 4). The concentrations of total N and reduced N, and the yield of reduced N per plot, increased significantly with increasing N-rates ($p < .01$ in all cases, Tables 2 and 4).

The concentration of nitrate-N in the plants was of course higher with nitrate-N than with ammonium-N ($p < .01$, Tables 2 and 4). With ammonium-N there were only small amounts of nitrate present, and, on average, N in nitrate amounted to 0.77o/oo of dry matter (DM). The nitrate present with ammonium fertilizer is assumed to be mainly due to the activity of microorganisms in the growth medium, although the relatively

Table 4. Mean squares from analyses of variance for four characters concerning concentrations of N in dry matter (DM). The appropriate variance ratios for tests of significance for each of the components can be found in Table 1

Item	DF	Kjeldahl-N g N/100g DM	Nitrate-N mg N/100g DM	Reduced N g N/100g DM	Reduced N mg N/plot
N-source (N_s)	1	6.4321**	530278.35**	10.6560**	20563.24**
N-rate (N_r)	2	25.5909**	201093.35**	21.3281**	48157.52**
$N_s \times N_r$	2	4.0781**	131207.76**	5.6034**	6532.27**
Residual 1	6	0.1124*	4386.26**	0.0892	344.36
Between groups (G_a)	2	0.9984**	17848.60	0.9081	40973.48
Within groups (G_w)	3	0.1231	8320.68	0.1281*	7912.38**
$G_a \times N_s$	2	0.0011	9180.93	0.0117	7342.26**
$G_w \times N_s$	3	0.0530	16089.79	0.0254	2940.81
$G_a \times N_r$	4	0.2317**	6165.06	0.2028**	6310.20**
$G_w \times N_r$	6	0.0949	4695.10	0.0817	1748.05 (1
$G_a \times N_s \times N_r$	4	0.0445 (1	1848.85	0.0317 (1	3929.97*
$G_w \times N_s \times N_r$	6	0.0491 (1	5947.21**	0.0333 (1	1037.68 (1
Residual 2	30	0.0451	804.00	0.0441	1556.15
Pooled error (DF)		0.0457(40)		0.0412(40)	1509.50 (42)

1) Included in pooled error
* $p < .05$
** $p < .01$

small effect of increasing N-rates with ammonium, (cf. Fig. 1b), may suggest a nearly constant level of internal oxidation in the plants.

Interaction between N-source (N_S) and N-rates (N_r) was non- significant for yields (FW and DW), for number of tillers, and for tiller weight (Table 3). However, for the three characters concerning concentration of N in DM, and for yield of reduced N per plot, the interaction $N_S \times N_r$ was significant ($p < .01$ in all cases, Table 4). With ammonium-N the concentrations of total N and reduced N, and the yield of reduced N per plot, increased near linearly with increasing N-rates; with nitrate-N the increase was less for the same N-rates, and response tended to be curvilinear (Fig. 1a, c, d). The concentration of nitrate-N in DM was near linearly related to N-rates with nitrate fertilizer, whereas with ammonium the effect of N-rates was relatively small, as mentioned previously (Fig. 1b).

B. Clones, main effects, and interactions withnitrogen treatments

1. Fresh and dry weights of yields

For fresh weight (FW) and dry weight (DW) of yields, the effects of groups are of borderline significance when tested against the interaction $G_W \times N_S$, ($.05 < p < .01$, and $.10 < p < .05$ for FW and DW respectively; Table 3). Of the total sum of squares among clones, 60.8% was associated with the item G_a for FW, and 67.1% for DW. (If there is no effect of groups the expectation is 40%.) The variation within groups was not statistically significant for these two characters, but the within group mean square was considerably greater than for any of the interactions. And, as can be seen from the clonal means in Table 5, the median group was much more heterogeneous than the high and low groups.

A further partitioning of the within group sum of squares is shown for FW in Table 6. Here it is evident that the larger part of the sum of squares (SS), is

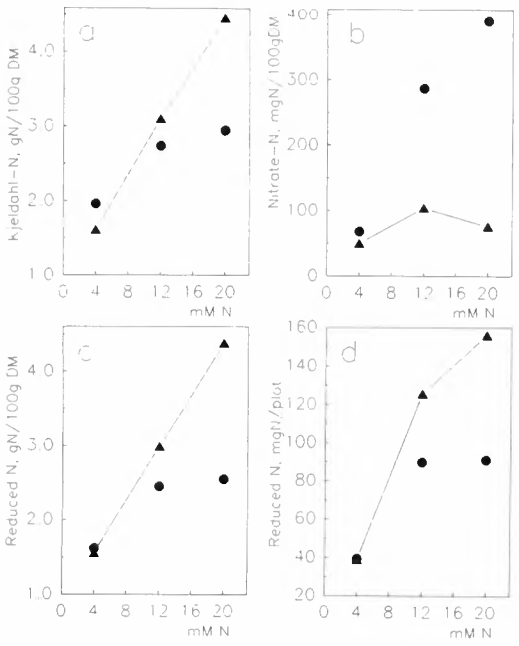

Fig. 1. Interaction between N-sources and N-rates for three traits concerning concentration of N in dry matter (DM), (a, b, and c), and for total amount of reduced N harvested per plot, d. The N-sources are ammonium-N filled triangles, and nitrate-N filled circles

(95.7% of the SS for within group variability). For DW (partitioning not given) the corresponding figure is 93.0%. Judging from the performance of the clones in the field, one would not expect the median group to be any more heterogeneous than either of the other two (Table 5, last line).

It can be concluded that for FW and DW of yields there are significant differences among the genotypes, although statistically of borderline significance; a major part of the genetic differences is accounted for by the differences among groups.

The interaction between groups and N-source was non-significant, but the interaction of within group differences by N-source was significant for both FW and DW (Table 3 and Fig. 2). Of the total SS for interaction between genotypes and N-source, 67.9% was associated with the item $G_w \times N_s$ for FW and 72.4% for DW.

The groups responded significantly differently to the N-rates, but there was no significant interaction of the within group differences with N-rates (Table 3). Of the total SS for interaction between genotypes and N-rates, 59.3% was associ-

accounted for by the median group

Table 5. Means of groups and of each clone averaged over nitrogen treatments for eight characters. (Overall means as in Table 2). Clones 123 and 117 constitute the high yielding group (H), 164 and 109 the intermediate group (M), and 140 and 101 the low group (L)

	Group means			Clonal means					
				H		M		L	
Character	H	M	L	123	117	164	109	140	101
FW 1. cut, g/plot	17.96	11.40	8.42	18.41	17.50	5.98	16.81	7.36	9.48
DW 1. cut, g/plot	4.60	2.76	2.43	4.80	4.40	1.65	3.88	2.20	2.66
No. of tillers/plot	15.8	11.9	9.8	15.7	15.8	11.2	12.5	9.8	9.8
DW, g/10 tillers	3.02	2.43	2.52	3.13	2.91	1.70	3.14	2.32	2.71
Kjeldahl-N, gN/100g DM	2.91	2.84	2.52	2.80	3.00	2.77	2.90	2.49	2.55
Nitrate-N, mgN/100g DM	148.	194.	145.	164.	133.	176.	212.	123.	168.
Reduced N, gN/100g DM	2.75	2.65	2.38	2.64	2.87	2.60	2.69	2.37	2.39
Reduced N, mgN/plot	136.9	74.5	58.8	132.7	141.1	44.9	104.0	48.9	68.6
Annual yield, FW, in the field, 100g/plot	59.81	47.83	28.45	60.0	59.6	47.8	47.8	24.8	32.1

Table 6. ANOVA for data of yild at first harvest, fresh weight in g/plot

Source of variation	DF	SS	MS	DF	MS Within groups H	M	L
Total	71	3824.2275					
Between boxes	11	556.4118					
N-source (N_s)	1	11.5280	11.5280				
N-rate (N_r)	2	521.8130	260.9065**				
N_s x N_r	2	2.2213	1.1107 (1				
Residual A	6	20.8495	3.4749 (1				
Within boxes	60	3267.8156					
Clones	5	1878.9736	375.7947				
Between groups (G_a)	2	1143.0949	571.5474*				
Within groups (G_w)	3	735.8788	245.2929	1	5.0233	704.0583*	26.7971
Clones x N_s	5	234.7481	46.9496				
G_a x N_s	2	75.2958	37.6479				
G_w x N_s	3	159.4523	53.1508*	1	36.3589	50.4310	72.6624*
Clones x N_r	10	330.5329	33.0533				
G_a x N_r	4	196.1741	49.0435*				
G_w x N_r	6	134.3588	22.3931	2	20.1469	26.0462	20.9864
Clones x N_s x N_r	10	327.1198	32.7120				
G_a x N_s x N_r	4	192.7802	48.1950*				
G_w x N_s x N_r	6	134.3396	22.3899 (1	2	19.4727	44.3431	3.3541
Residual B	30	496.4412	16.5480				
Error pooled	50		15.7642				
Error pooled	36		14.3692				

* $p < .05$
** $p < .01$

ated with the item G_a x N_r for FW, and 62.5% for DW.

The three-factor interaction G_a x N_s x N_r was also significant for both FW and DW, while the G_w x N_s x N_r was not (Table 3). The interaction of groups with N-rate and N-source is illustrated for yields of FW in Fig. 3. The picture here is somewhat complex, and it is difficult to see which group responded most favourably to changes in the environment. This may be easier to see from a linear regression of group means on an environmental index, applying the method referred to in the Introduction.

For a regression analysis of group responses to environments, FW of yields at two successive cuts on three N-rates and two N-sources is used, comprising a total of twelve environments. The results in Table 3 indicate that N-rates produce greater environmental differences than N-sources for this character. The regression of group performance on an environmental index shows that the trend throughout the environments was for the groups to be ranked H > M > L, and that the response increased with increasing field performance (Fig. 4). The regression coefficient of the high group was significantly greater than unity, and that of the low group significantly less, while the regression of the median group did not deviate significantly from unity.

2. Number of tillers

There were significant differences among groups for the character number of tillers per plot; the groups were ranked H > M > L. Of the total SS among genotypes, 97.6% was associated with the item G_a. The within group variability was very small for this character, and, compared with the others, the performance of clone No. 164 was more in accordance with what one might expect from its field performance (Table 5). The results suggest that tillering capacity, as measured

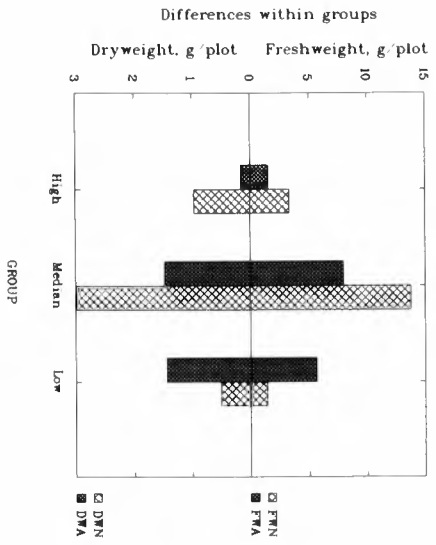

Fig. 2. Interaction of genotypes within groups by N-source for fresh weight (FW) and dry weight per plot (DW). Genotype differences within groups are given for ammonium-N (FWA, DWA) and nitrate-N (FWN, DWN). The groups are of high, median, and low field performance for yield

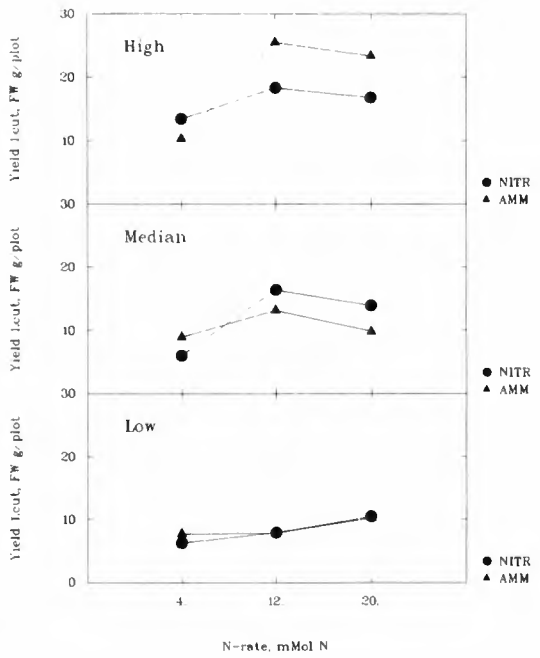

Fig. 3. Three-factor interaction of groups of genotypes by N-source by N-rate for the trait fresh weight of yield at first cut (FW g/plot). The high - (H), median - (M), and low-yielding groups (L) were supplied with ammonium-N (A) and nitrate-N (N) in concentrations of 4, 12, and 20 mM N, respectively

in the present experiment, might have been an important component of yield as measured in the field experiment.

None of the interactions were clearly significant for this character. However, a pooled estimate of $G_w \times N_s \times N_r$, either with 10 or 28 degrees of freedom, was significant ($p < .05$). This three-factor interaction is illustrated in Fig. 5.

3. Weight of individual tillers

The weight of individual tillers, measured as yield of DM per ten tillers, ranked the groups H > M > L, but the variation among groups was not significant (Tables 5 and 3, respectively). There was, however, significant variation within groups; and the median group which contained the two extreme divergent clones for this character contributed the larger part of the SS (91.2%). The mean square of $G_w \times N_s$ was suspiciously large, and a pooled estimate of this with 5 d.f., was significant ($p < .05$, see Fig. 6). None of the other interactions were significant for this character. Further, the coefficient of variation was less than for any of the other three characters discussed previously. This suggests that weight of the tillers may be a selection criterion which ranks the genotypes more consistently over the environments than for instance yield per plant or per clonal plot.

4. Nitrogen content of the plants

a. Kjeldahl-N

The total N-content of the plants varied significantly among groups, and the group means were ranked H > M > L (Tables 4 and 5). Of the total SS among clones, 84.4% was associated with the item G_a. Mean square of item G_w was also considerably greater than the error, but not significantly so ($.10 > p > .05$).

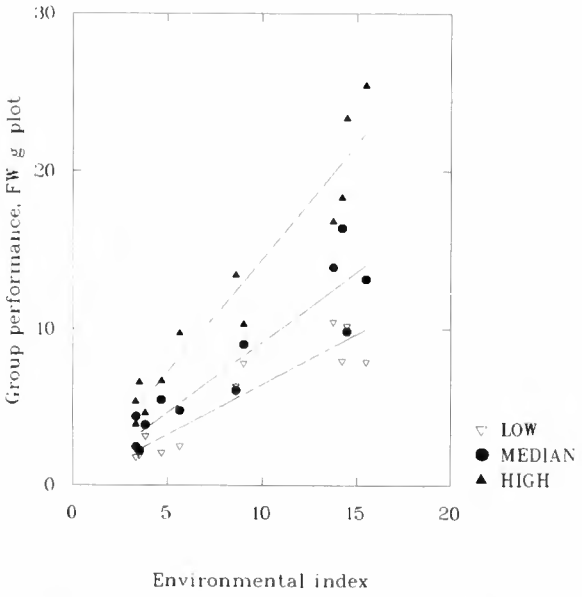

Fig. 4. Linear regressions for three groups of genotypes on 12 environments comprising two successive cuts on two N-sources and three N-rates. The groups are of high - (filled triangles), median - (filled circles), and low field performance (filled, inverted triangles)

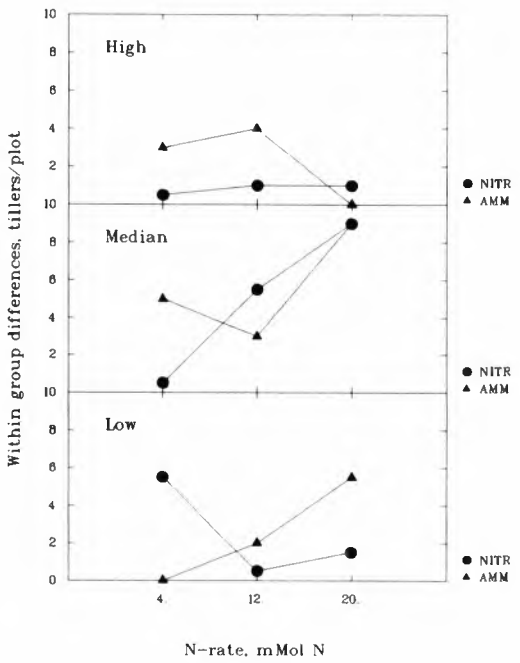

Fig. 5. Three-factor interaction of genotypes within groups by N-source by N-rate for the trait number of tillers per plot. The groups are of high (H), median (M), and low field performance for yield, and were treated with ammonium-N (A) or nitrate-N (N) in concentrations of 4, 12, and 20 mM N, respectively

There was a significant interaction between groups and N-rates, but not between genotypes within groups and N-rates (Table 4). Of the total SS for interaction between clones and N_r, nearly 62% was associated with the item G_a x N_r.

From Fig. 7 it can be seen that the total N-content of the plants increased more with an increasing supply in the high and median groups than in the low group. In terms of nitrogen efficiency, i.e. DW produced per unit of nitrogen assimilated, the low group should be the most efficient. However, all the genotypes within each nitrogen treatment received approximately the same supply of nitrogen. With the procedure used here, the competition was probably weak, and the results may rather indicate that the high and median groups were more efficient in assimilating the supplied nitrogen than the low group.

b. Nitrate-N

The only clearly significant effect for this character was the three-factor interaction between genotypes within groups, N-source and N-rates (Table 4). There was no significant effect of groups, although for the clonal means there was no overlap between the median group, on the one hand, and the high and low groups, on the other (Table 5). Consideration of the results for each separate clone suggests that there may be considerable genetic variation in nitrate concentration among plants, although the tests here have not produced the basis for any conclusion about significant main effects of genotypes (see Fig. 8, and for instance clones 140 and 109 in Table 5).

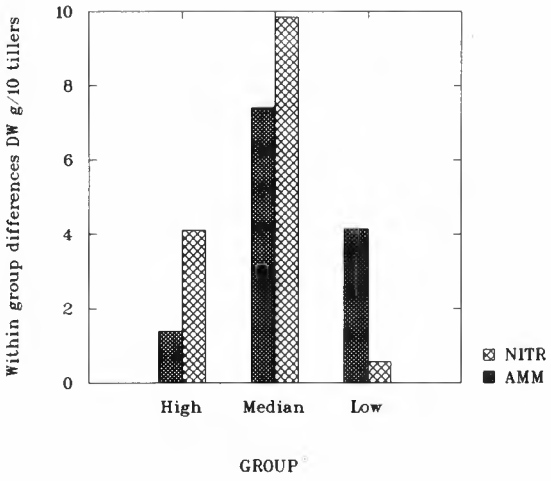

Fig. 6. Two-factor interaction of genotypes within groups by N-source for the trait dry weight (DW) per 10 tillers. Groups and N-sources as in Fig. 2

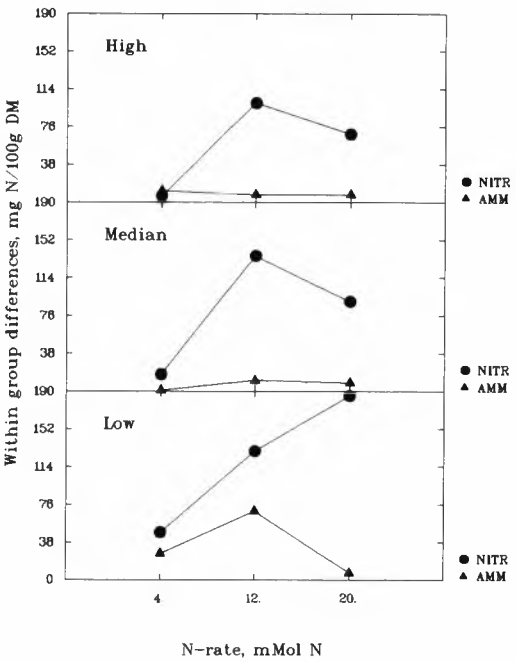

Fig. 8. Three-factor interaction of genotypes within groups by N-source by N-rate for the trait concentration of nitrate-N in plants (mg N/100 g DM). Groups, N-sources, and N-rates as in Fig. 3

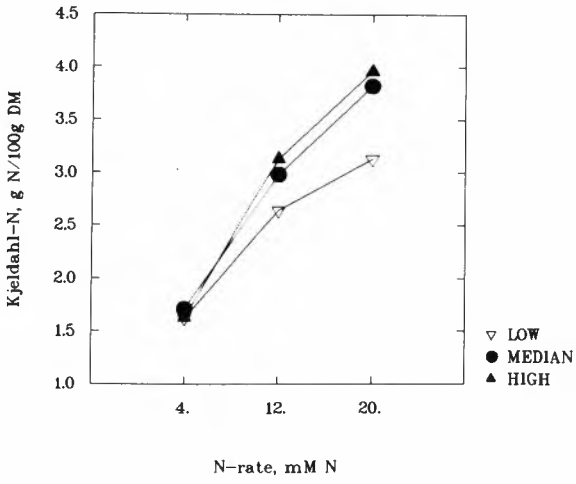

Fig. 7. Mean concentration of total N in plants of the high (H), median (M), and low (L), groups supplied with 4, 12, and 20 mM N, respectively. Datapoints are averaged over two genotypes, two N-sources, and two replicates

c. Reduced nitrogen

There was a significant genetic variation within groups for the concentration of reduced N in dry matter ($p < .05$), and the mean square of the item G_a was suspiciously large, but the effects of groups were not significant ($.10 > p > .05$, Table 4). Of the total SS among genotypes, 82.5% was associated with the item G_a. The group means were ranked H > M > L, as for Kjeldahl-N.

Among the interactions, the only significant one was that between groups and N-rates (Fig. 9). The responses of the groups to increasing N-rates were in order H > M > L, similar to the same interaction for Kjeldahl-N (Fig. 7). That the difference in response between the high and median groups was slightly greater for reduced N than for Kjeldahl-N is of course a consequence of the somewhat higher content of nitrate in the median group (Table 5 and Fig. 8).

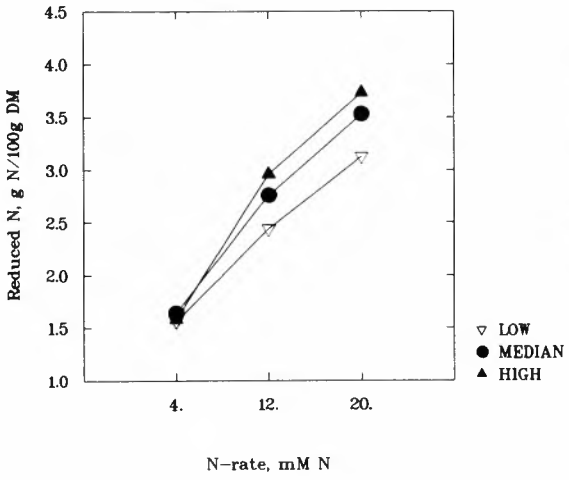

Fig. 9. Two-factor interaction of groups of genotypes by N-rate for the trait concentration of reduced N in plants (g N/100 g DM). Groups, N-rates, and datapoints as in Fig. 7

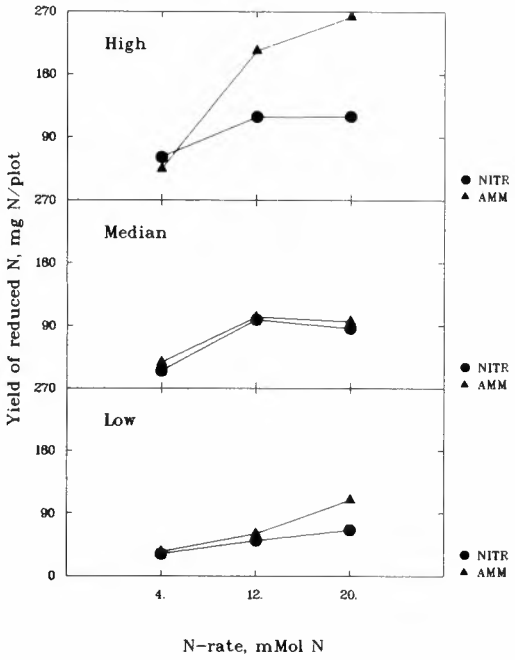

Fig. 10. Three-factor interaction of groups of genotypes by N-source by N-rate for the trait yield of reduced N (mg N/plot). Groups, N-sources, and N-rates as in Fig. 3

5. Yield per plot of reduced nitrogen

For this character there was a significant genetic variation within groups ($p < .05$), but not between them, although 77.5% of the SS among clones was associated with the item G_a (Table 4). The group means were ranked as H > M > L, with an overlap in clonal means between the low and the median groups (Table 5).

The interactions between groups and N-sources ($p < .01$), between groups and N-rates ($p < .01$), and also the three factor interaction $G_a \times N_s \times N_r$ were all significant ($p < .05$). Of the total SS for the interactions in the same order as above, 62.5% was associated with the item $G_a \times N_s$, 70.6% with $G_a \times N_r$, and 71.6% with $G_a \times N_s \times N_r$, respectively. The interaction between groups and nitrogen treatments is illustrated in Fig. 10.

Perhaps a clearer illustration of differences between groups in response to overall environmental changes can be found in the linear regressions shown in Fig. 11. It is evident from part a in the figure that on average the high group shows a stronger response to environmental changes than the other two. But in this «average» regression some information about the three-factor interaction is masked. When the group performances are regressed on environments within N-sources, it is evident that the high group had a significantly stronger response to N-rates with ammonium fertilizer than with nitrate (Fig. 11b). For the median group, the tendency was the opposite, while the low group showed only minor differences between the two N-sources. However, with the few degrees of freedom for each analysis within N-source, only the regressions for the high group were significant, although in all cases, except one, the regressions described more than 91% of the variation among N-

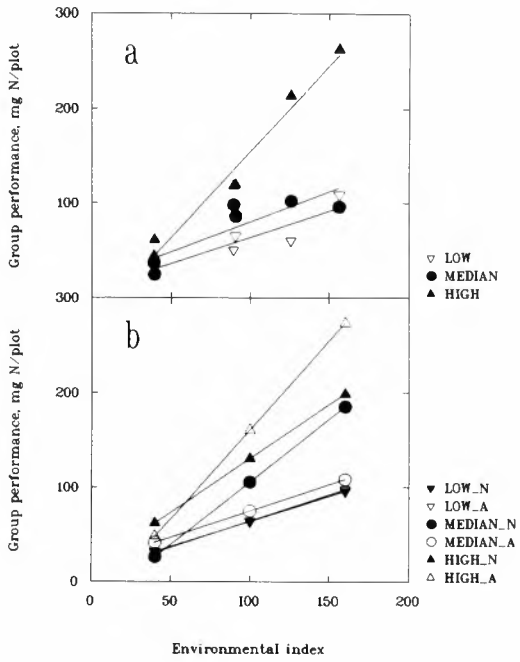

Fig. 11. (a. Regressions of group means on six environments comprising two N-sources and three N-rates for the trait yield per plot of reduced N (mg N/plot). (b. Regressions of group means within N-sources on environments, comprising N-rates, for the same trait as in (a. (Datapoints are omitted.) Groups, N-sources, and N-rates as in Fig. 3

rates within groups. The difference between groups H and M seems mainly to arise from the different behaviour of clones 117 and 109, the former reacting in an «ammonium nitrophilous» way, the latter in a «nitrate nitrophilous» way. Tendencies toward such differences were also discernible among other clones, but were less evident.

DISCUSSION

The two N-sources differ in the uptake mechanism involved and in the way they enter the anabolic pathways in the plants. Ammonium-N mainly circumvents the presumably limiting step of reduction which nitrate-N must pass through. This is reflected in the higher level of N-balance in plants given NH_4^+-N compared with NO_3^--N. Also, the (near) linear increase in N-content of plants given ammonium as compared with the curvilinear response of those given nitrate probably reflects the limiting rate of NO_3^- reduction, although it is confounded with differences in the uptake. The main consequences of the higher N-balance in this experiment appear to be increased tillering and an increased recovery of supplied N.

The main interest in this experiment, however, is in the differences between genotypes and their interaction with N-treatments. Although the clones were cut down to single tiller ramets and given a pre-experiment period with equal treatment, a carry-over of effects from the field experiment cannot be excluded.

With a rather complex model for observations in the experiment, one is left with relatively low discriminating power in the statistical tests. Or, in other words, an effect has to account for a large proportion of the variation to be found significant with the degrees of freedom left for the individual tests. Sums of squares are therefore pooled when appropriate to improve the discriminating power of some of the tests. Although this may be seen as «scraping for significance». I think it can be justified in the present situation.

It should be noted that the groups largely perform in accordance with expectations from the field experiment, and that the interactions involving groups often do not involve a change in rank among them. When a change in rank does occur, it is close to the extreme of the environmental range imposed in the experiment.

The group selected for high yield in the field experiment was also the one with the highest response to N. That is to say, the high yielding group is expected to return more for increased fertilizer-N than any of the other groups, or to give the highest yield at any reasonable N-rate used in commercial production. As

competition in the root zone in this experiment was virtually absent, it also suggests that the higher yielding genotypes are better able to extract nutrients from the available volume than the low yielding genotypes.

The within groups variation, however, was considerable for some traits. That is to say, significant group attributes do not necessarily apply to random individual genotypes in this case.

The median group, which was represented with the most uniform phenotypic values from the field, appeared as the most variable for some of the traits investigated in the present experiment. This is to be expected, as an intermediate phenotype gives room for more complementary or compensatory combinations of components of a complex trait than extreme phenotypes at either end of the distribution. However, it also underlines the difficulties in phenotypic selection for a complex, quantitative trait, and also emphasizes the benefit of applying a low selection intensity in population breeding.

SUMMARY

From a field experiment assessing yields of 200 randomly selected clones of cocksfoot, *Dactylis glomerata* L., two clones were selected from the high-, median-, and low-yielding groups, respectively. Single tiller ramets from these clones were planted in plastic boxes filled with inert sand and subjected to six different N-fertilizer treatments. These comprised the factorial combinations of two N-sources, NH_4^+ and NO_3^-, and three N-rates, 4 mM, 12 mM, and 20 mM of N, in nutrient solution. There were two complete replicates. A mixed and split model for observations and ANOVA is presented, which allows explicit testing for the significance of all the identified effects of genotypes and environments.

There was no significant effect on yield, either fresh or dry weight, of N-source. However, 12 and 20 mM N gave significantly higher yields than 4 mM N in the nutrient solution.

Ammonium-N gave more tillers per plant than NO_3^--N, and the highest concentrations gave more tillers than the lowest. Nitrate-N gave heavier tillers than NH_4^+-N, whereas N-rates had no significant effect on tiller weight.

Interactions between N-sources and N-rates were significant for three measures concerning concentration of N in dry matter, and for yield per plot of reduced N.

It is concluded that the three groups of genotypes produced different yields, although the variation among them was statistically of borderline significance. The group mean yields were ranked as in the field experiment. There was also a significant interaction between groups and N-rates for yield, as well as a significant three-factor interaction; differences between groups x N-sources x N-rates.

For number of tillers per plant there was also a significant variation between groups, and the group means were ranked as for yield. None of the interactions were clearly significant for this character.

The dry weight per tiller also ranked the group means as for yield, but the variation between groups was not significant. The variation within groups was significant, however. This character also had the smallest coefficient of variation of the different measurements for yield.

The total N-content of plants varied significantly between groups, and the group means were ranked as for yield performance in the field. The groups also interacted significantly with N-rates for this trait.

For the concentration of NO_3^--N in plants, the only significant variation was that of the three-factor interaction of differences between genotypes within groups x N-source x N-rates. Yield per plot of reduced N revealed a significant genetic variation within groups, but not between them.

Several components of genotype environment interactions were found to be significant for various characters, and they are illustrated in simple regression graphs or in bar graphs.

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Barley-fodder rape silage

I. Ensiling studies

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A mixed crop of barley and fodder rape (average ratio 1:4) was ensiled at five sites in Northern Norway during the period 1982-84. Two barley cultivars and three harvesting stages - one week after heading of barley (H1), dough ripening (H2) and yellow ripening (H3) - were compared by examining crop yield and composition, ensiling ability and nutritive value of the silage. At the northernmost sites the barley did not always reach the yellow ripening stage. Dry matter (DM) yield increased up to dough ripening. All silages had good preservation quality. DM content of the crop and the silage increased with delayed harvesting. At the second and third harvesting times crude protein content was below 10% of DM. Effluent losses decreased substantially with delayed harvesting. At the two southernmost sites the values for average digestibility of organic matter were 72.6, 66.6 and 61.6% at H1, H2 and H3, respectively. At the three northernmost sites mean organic matter digestibility were 75.1 at H1 and 70.3% at H2.

Key words: Whole barley, fodder rape, mixed cropping, silage, chemical composition, digestibility

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Animal husbandry systems in Northern Norway are based on grassland production, but because of the severe climate, grass often does not survive the winter. A number of farmers therefore make use of annual crops for feed production.

While whole crop barley (*Hordeum vulgare* L.) gives silage of acceptable quality (Kristensen et al. 1979, Mo 1982), practical experience shows that this silage is prone to moulding and secondary fermentation following opening of the silo.

In an attempt to increase the stability of the silage, fodder rape (*Brassica napus* var. *oleifera* L.) has been sown with barley to produce a mixed crop better suited to ensilage. In field trials barley and fodder rape gave high yields with an adequate percentage of fodder rape (Hagsand 1977, Østgård 1980). In a preliminary trial at Vågønes Research Station in Northern Norway mixed cropping of barley and rape produced a well-conserved silage with a satisfactorily high energy content (Hole 1982).

It was on the basis of this that the project entitled «The use of barley-fodder rape silage for cattle and sheep in Northern Norway» was started. Financed by the Agricultural Research Council of Norway (NLVF), the project aimed at providing more information about conservation and the feed value of whole barley-fodder rape silage. Three ensiling trials were conducted along with ten production experiments which included four

with growing bulls, three with dairy cows and three with sheep.

The ensiling experiments were carried out at the Norwegian State Agricultural Research Stations at Tjøtta (66°N), Vågønes (67.1°N), Holt (69.5°N), Flaten (70°N) and Svanhovd (69.3°N). A comparable series of experiments was conducted in Southern Norway at the same time (Lunnan 1983, Pestalozzi unpublished).

The purpose of this work was to gain information about how nutritive value, ensiling ability, crop composition and crop yield of the barley-fodder rape mixture are influenced by harvesting stage, barley cultivar and varying growing conditions.

The bull and dairy cow experiments were conducted at Vågønes, and the experiments with sheep at Tjøtta. This report details the ensiling and digestibility experiments; results from the bull and dairy cow experiments in this series are given in reports II and III (Nordang 1990a, b). The sheep feeding experiments will be published elsewhere.

MATERIALS AND METHODS

A. Plan of experiments

Using a factorial design, three ensiling experiments were carried out in the period 1982-84, with the variables harvesting stage (H1 to H3), research station, year, and two barley varieties, Bode and Lise, as indicated in the following diagram.

	Harvesting stage		
	H1	H2	H3
Research station	One week after heading	Dough ripeness	Yellow ripeness
Tjøtta	x	x	x
Vågønes	x	x	x
Holt	x	x	
Flaten	x	x	
Svanhovd	x	x	

At the three northernmost stations (Holt, Flaten and Svanhovd) the barley reached the yellow ripeness stage in only a few cases, so this treatment was not included in the final analysis.

The mixed sward of barley and fodder rape was established by sowing 100 kg ha^{-1} of barley seed and 10 kg ha^{-1} fodder rapeseed (cv. Kentan). Nitrogen (120 kg N ha^{-1}) was applied in spring as complex fertilizer (P and K at a rate of 52 and 140 kg ha^{-1}, respectively) prior to sowing. At each station the two barley cultivars were sown in adjacent plots in the same field.

B. Growing conditions

The Agricultural Research Stations at Tjøtta, Vågønes and Holt are located on the coast and have a maritime climate; Flaten and Svanhovd have a more inland type of climate. Precipitation and temperature at the different stations are given in Table 1 (Det norske meteorologiske institutt 1982, 1983, 1984).

The three summers were among the coldest recorded this century, with precipitation generally higher than normal at Tjøtta, Vågønes and Holt; the spring seasons tended to be drier than normal. At the Finnmark stations, Flaten and Svanhovd, the precipitation was lower than, or equal to the average for the same period.

C. Methods

This study was conducted using methods similar to those described by Bergheim (1979) and Hole (1985). Prior to harvesting, samples of about 10 kg herbage were obtained and the botanical composition analysed by sorting. The barley plants were separated into ears and stems plus leaves, and the rape plants into leaves and stems. Two areas within each field, each about 10 m^2, were harvested to determine the dry matter (DM) yield.

The crops were harvested using a forage flail harvester and ensiled in solid plastic silos (diameter = 0.8 m, height = 1.5 m), each with a holding capacity of 200-300 kg silage. Each silo had a double

Table 1. Precipitation and temperature at the different experimental stations

Station	Temperature, °C					Precipitation, mm				
	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
TJØTTA										
Standard Normals	7.2	10.5	13.7	13.2	10.0	77	89	94	110	146
1982	7.1	8.7	13.0	12.5	8.9	112	33	161	98	27
1983	19.4	9.5	12.2	10.9	10.5	80	106	147	327	192
1984	10.4	10.6	11.3	12.0	9.6	48	106	117	221	131
VÅGØNES										
Standard Normals	6.2	9.9	13.6	12.7	9.4	49	69	70	97	126
1982	6.3	7.7	11.7	12.2	8.3	84	37	191	73	192
1983	9.6	9.0	11.4	10.0	10.4	49	92	121	225	116
1984	9.8	10.7	10.9	11.4	9.0	41	59	136	138	70
HOLT										
Standard Normals	4.1	8.8	12.4	11.0	7.2	61	59	56	80	109
1982	4.0	5.5	11.5	10.1	5.3	44	60	107	68	167
1983	7.0	8.3	11.5	8.6	8.5	34	69	106	195	70
1984	7.9	9.6	9.8	10.3	6.5	41	83	67	129	75
FLATEN										
Standard Normals	4.6	10.1	14.3	12.2	7.5	26	35	49	45	40
1982	4.7	6.3	13.7	11.6	6.1	37	9	68	49	104
1983	5.7	10.1	13.6	10.2	9.3	11	20	18	38	27
1984	-	10.9	11.9	11.5	6.7	-	63	43	21	9
SVANHOVD										
Standard Normals	4.2	10.8	14.4	12.3	6.7	24	53	56	63	38
1982	3.8	5.9	14.6	10.8	6.2	36	46	81	62	98
1983	4.9	10.4	14.3	10.3	8.4	27	33	66	51	35
1984	7.9	11.2	12.0	10.7	5.7	36	31	109	63	18

bottom, the upper one being perforated to allow collection of effluent.

The plant material was loaded into the silos (one silo at each treatment) in portions of 10 kg, a small amount of material being collected from each portion to provide a composite sample of the ensiled crop. Formic acid (85%) diluted with water (1:9) was added at a rate of 3.0 l 85% formic acid ton^{-1}. A plastic sheet was laid along the sides of the silo before the last three portions of herbage were added, and folded towards the middle when the silo was closed. The plastic sheet was covered with a lid of solid plastic and a weight corresponding to 500 kg m^{-2} was placed on the top of each silo immediately after closure.

Collection and weighing of effluent was carried out 6-7 times before the silos were emptied. Samples from each tapping were mixed to an aliquot sample from each silo.

Digestibility trials were carried out using two adult wether sheep fed at the maintenance level on each silage. The faeces were collected over ten days, after an adaptation period of eleven days.

The chemical analysis of freshly cut crops, effluent and silage was carried out at the Chemical Laboratory at Holt Agricultural Research Station. The methods used in the analysis are described by Rasjonaliseringsutvalget for Statens landbrukskjemiske kontrollstasjoner av 1960 (1964), with later modification (Lysnes pers. comm.). Organic acids in the silage were determined using gas chromatography. Silage DM was corrected for losses of volatile substances according to Ekern (1972), assuming that 80% of the formic, acetic, butyric, propionic and valeric acids are lost during ovendrying at 103-105°C.

Crude protein in the silage was estimated as Kjeldahl-N x 6.25, while correc-

ted crude protein was estimated by subtracting NH_3-N from Kjeldahl-N before multiplying by the factor 6.25. True protein was determined as Kjeldahl-N x 6.25 following hot water treatment of fresh crops or silage. The content of sugar was determined as the total amount of reducing sugars. Buffering capacity was determined using the method of Playne & McDonald (1966).

Estimates of the energy value of the silage are based on the data from chemical analyses and coefficients of *in vivo* digestibility. The net energy, given as fattening feed units (FU), was calculated by using the following factors (g digestible nutrients)$^{-1}$: 2.24 NK_F for crude protein and 2.36 NK_F for crude fibre, ether extract, and N-free extract (Kellner 1905, Poijärvi 1934). The content of FU was calculated by using a value number of 80, or a crude fibre deduction of 1.04 NK_F (g crude fibre)$^{-1}$ (Presthegge 1959).

Metabolizable energy (ME) was estimated according to the regression equation given by Rostock workers (Schiemann et al. 1971). The factors kJ (g digestible nutrients)$^{-1}$ were: 18.07 for crude protein, 15.02 for crude fibre, 15.19 for N-free extract. For ether extract in silage the factor 20.92 was used, in accordance with Eriksson (1946).

D. Statistical treatment of the data

The statistical analysis of the data was carried out using the General Linear Models procedure described by SAS (1985).

The following model was used:

$$Y_{ijkl} = \mu + a_i + b_j + c_k + d_l + (ab)_{ij} + (ac)_{ik} + (ad)_{il} + (bc)_{jk} + (bd)_{jl} + (cd)_{kl} + e_{ijkl}$$

where

Y_{ijkl} = the parameter analysed
μ = general mean
a_i = the effect of the i-th year
b_j = the effect of the j-th harvesting stage
c_k = the effect of k-th station
d_l = the effect of l-th barley cultivar
$(ab)_{ij}$ - $(cd)_{kl}$ = the interaction between the factors
e_{ijkl} = random error

Since there was an imbalance in the data, the data for the southernmost stations (Tjøtta and Vågønes) and the three northernmost stations (Holt, Flaten and Svanhovd) were analysed separately.

The values are presented as least square means (LS means), and differences between the LS means are tested by multiple t-tests; those with different superscripts indicate a significant difference ($P < 0.05$). The coefficient of determination (R^2) for each analysis is also presented, giving the proportion of the total variation explained by the statistical model.

RESULTS

A. Harvesting date, crop yield, botanical and morphological composition

Harvesting date, crop yield, botanical and morphological composition on the basis of DM are given in Tables 2 and 3.

Compared at the same ripening stage, the harvesting date was earlier at the two southernmost stations than at the three northernmost ones. There was an increase in DM yield by postponing harvesting from harvesting stage 1 (H1) to harvesting stage 2 (H2), but no further increase was observed by later harvesting.

The proportion of rape in the mixtures varied considerably between stations and years, but not between barley varieties and harvesting stages. This reflected considerable differences in rape proportion between plots, caused by germination problems with rape during dry spring conditions.

Weeds created few problems, except at Vågønes where chickweed (*Stellaria media* Vill.) represented considerable amounts of crop DM in 1982 and 1983. Ears as a percentage of barley plants increased with harvesting date, with the proportion higher at the southern than at the northern stations at the same harvesting stage. A tendency towards higher ear proportion was observed for the

Table 2. Harvesting date, crop yield, botanical and morphological composition. LS means, Tjøtta and Vågønes

	Harvesting date	Crop DM yield ton ha^{-1}	% of DM			Ears, % of barley DM	Leaves, % of rape DM
			Rape	Barley	Weeds		
Harvesting stage							
1	3.8.	5.1^{a}	17.1	73.4	9.5	15.6^{a}	72.8^{a}
2	25.8.	7.0^{b}	17.5	73.6	8.9	31.6^{b}	56.0^{b}
3	18.9.	7.0^{b}	21.7	69.8	8.6	41.4^{c}	48.0^{c}
Station							
Tjøtta	22.8.	6.8^{b}	20.8	73.5	5.7^{a}	33.3^{b}	56.9^{a}
Vågønes	28.8.	5.9^{a}	16.7	70.9	12.4^{b}	25.8^{a}	61.0^{b}
Year							
1982	4.9.	6.2^{a}	19.3	66.9	13.9^{b}	28.1	60.1^{b}
1983	18.8.	5.7^{a}	20.3	68.5	11.2^{b}	30.3	56.7^{a}
1984	21.8.	7.1^{b}	16.7	81.3	2.0^{a}	30.2	60.1^{b}
Variety							
Bode	21.8.	6.3	19.5	71.8	8.6	31.1^{a}	59.7
Lise	29.8.	6.4	18.0	72.6	9.4	27.9^{b}	58.2
Mean	25.8.	6.4	18.7	72.2	9.0	29.5	59.0
R^2	0.99	0.78	0.75	0.83	0.91	0.96	0.95

Table 3. Harvesting date, crop yield, botanical and morphological composition. LS means, Holt, Flaten, Svanhovd

	Harvesting date	Crop DM yield ton ha^{-1}	% of DM			Ears, % of barley DM	Leaves, % of rape DM
			Rape	Barley	Weeds		
Harvesting stage							
1	13.8.	3.8^{a}	21.4	75.9	2.7^{a}	12.5^{a}	75.2^{a}
2	7.9.	6.5^{b}	24.2	74.2	1.6^{b}	17.3^{b}	58.4^{b}
Station							
Holt	27.8.	-	22.2^{ab}	74.1^{ab}	3.7^{b}	12.4^{a}	66.8
Flaten	23.8.	5.8	31.5^{b}	67.4^{a}	1.0^{a}	17.5^{b}	-
Svanhovd	29.8.	4.5	14.8^{a}	83.6^{b}	1.7^{a}	14.9^{ab}	-
Year							
1982	1.9.	5.0	26.1^{b}	73.4^{ab}	0.5^{a}	13.2^{a}	68.2^{b}
1983	25.8.	5.7	28.6^{b}	70.5^{a}	0.9^{a}	13.3^{a}	63.9^{a}
1984	22.8.	4.7	13.8^{a}	81.1^{b}	5.1^{b}	18.3^{b}	68.2^{b}
Variety							
Bode	25.8.	4.9	22.7	75.1	2.2	15.8	68.7
Lise	27.8.	5.3	22.9	75.0	2.1	14.0	64.9
Mean	26.8.	5.1	22.8	75.0	2.1	14.9	66.8
R^2	0.99	0.93	0.71	0.68	0.93	0.85	0.96

variety Bode compared to Lise, while leaf ratio in rape decreased with harvesting stage.

B. Chemical composition of the crops ensiled

Tables 4 and 5 give the chemical compositions of the ensiled crops. The DM percentage increased rapidly with increasing crop age. Because of low DM content in rape, a high proportion of rape in the mixture resulted in reduced DM content. No significant difference in DM content between the two barley varieties was observed.

Crude protein content decreased significantly from H1 to H2, while the further decrease to H3 was not significant. The crops from Flaten showed a higher content of crude protein than those from the other stations.

Although crude fibre content was higher at Tjøtta than at Vågønes, there were no significant differences between harvesting stages at these stations. The crude fibre content decreased from H1 to H2 at the three northernmost stations and was significantly different between stations, Holt showing the highest, Svanhovd the lowest value.

Ether extract was highest and N-free extract lowest at the H1 harvesting stage. At Tjøtta and Vågønes the sugar content decreased with increasing crop age, whereas at the other stations the sugar content increased from H1 to H2.

True protein as a percentage of crude protein showed an increasing trend with postponed harvesting. Buffering capacity decreased as harvesting was delayed, although considerable variation in this parameter was observed between stations and years.

C. Chemical composition and quality of the silage

The chemical compositions of the silages are given in Tables 6 and 7. DM content of the silage showed less variation than the corresponding DM content of the crops ensiled.

Table 4. Chemical composition of ensiled crops. LS means, Tjøtta and Vågønes

		In % of DM									
	DM, %	Crude prot.	True prot.	Crude fibre	Ether extr.	N-free extr.	Ash	Sugar	NO_3-N	Buffer cap.[1)]	True prot. % of CP
Harvesting stage											
1	15.0[a]	13.5[b]	9.6[b]	31.9	2.3[b]	44.4[a]	8.0[b]	12.2[b]	0.04[b]	37.0[b]	73.6[a]
2	17.8[b]	9.4[a]	7.2[a]	30.6	1.9[a]	51.0[b]	7.1a	8.8[a]	0.02[a]	30.7[a]	78.8[ab]
3	23.8[c]	8.4[a]	7.1[a]	32.4	1.8[a]	50.1[b]	7.3[ab]	7.4[a]	0.02[a]	27.9[a]	85.0[b]
Station											
Tjøtta	17.8[a]	10.9	8.5[b]	33.3[b]	2.0	46.0[a]	7.8[b]	9.1	0.03[b]	35.5[b]	78.1
Vågønes	19.9[b]	9.9	7.5[a]	30.0[a]	2.0	51.0[b]	7.1[a]	9.8	0.02[a]	28.2[a]	80.1
Year											
1982	20.5[b]	9.6	8.1	31.1[a]	1.8[a]	50.3[a]	7.2	10.1[b]	0.02	30.1	89.7[b]
1983	16.8[a]	10.9	8.1	29.6[a]	2.4[b]	49.3[a]	7.8	12.2[c]	0.02	31.9	74.2[a]
1984	19.3[b]	10.8	7.7	34.2[b]	1.8[a]	45.9[b]	7.4	6.0[a]	0.04	33.5	73.4[a]
Variety											
Bode	18.0[a]	10.6[a]	7.8[a]	31.9	2.0	48.0	7.5	9.2	0.03	31.4	75.3
Lise	19.7[b]	10.2[b]	8.2[b]	31.4	2.0	49.0	7.4	9.7	0.03	32.3	82.9
Mean	18.8	10.5	8.1	31.7	2.0	48.2	7.5	9.4	0.03	32.1	78.8
R^2	0.87	0.75	0.85	0.81	0.84	0.87	0.70	0.90	0.64	0.69	0.64

[1)] Meq (100 g DM)$^{-1}$

Table 5. Chemical composition of ensiled crops. LS means, Holt, Flaten and Svanhovd

		In % of DM									
	DM, %	Crude prot.	True prot.	Crude fibre	Ether extr.	N-free extr.	Ash	Sugar	NO_3-N	Buffer cap.[1)]	True prot. % of CP
Harvesting stage											
1	14.5[a]	14.2[b]	10.4[b]	30.0[b]	2.3[b]	44.1[a]	9.4[b]	12.6	0.10[b]	34.2[b]	75.9
2	19.4[b]	9.8[a]	7.8[a]	28.7[a]	1.7[a]	52.2[b]	7.5[a]	13.5	0.05[a]	27.7[a]	79.6
Station											
Holt	14.6[a]	12.1[b]	9.0[b]	33.2[c]	1.7[a]	45.2[a]	7.8[a]	13.3	0.05[a]	31.6[b]	75.7
Flaten	15.5[a]	14.6[c]	11.0[c]	28.3[b]	2.3[b]	44.5[a]	10.4[b]	12.6	0.15[b]	35.6[c]	77.8
Svanhovd	20.8[b]	9.3[a]	7.2[a]	26.7[a]	2.2[b]	54.8[b]	7.1[a]	13.3	0.02[a]	25.6[a]	79.7
Year											
1982	15.9[a]	12.4[b]	9.8[b]	30.3[b]	2.1	46.4[a]	8.7[b]	12.9	0.06	32.2[b]	82.3[b]
1983	16.7[a]	13.3[b]	9.7[b]	27.8[a]	1.9	48.1[ab]	8.9[b]	13.9	0.07	28.4[a]	74.3[a]
1984	18.3[b]	10.2[a]	7.7[a]	30.0[b]	2.1	49.9[b]	7.7[a]	12.4	0.09	32.3[b]	76.6[ab]
Variety											
Bode	17.2	11.8	9.0	28.7[a]	2.0	48.6	8.9[a]	12.7	0.06[a]	30.6	78.4
Lise	16.7	12.2	9.2	30.1[b]	2.0	47.7	8.0[b]	13.5	0.09[b]	31.3	77.0
Mean	17.0	12.0	9.1	29.4	2.0	48.2	8.4	13.1	0.07	31.0	77.7
R^2	0.96	0.92	0.96	0.91	0.90	0.92	0.91	0.64	0.89	0.90	0.69

[1)]Meq (100 g DM)$^{-1}$

On average, crude protein content in DM decreased from 10.5 to 9.9% at Tjøtta and Vågønes, and from 12.0 to 11.0% at the other three stations, in fresh crop and silage, respectively. In addition, while the content of crude protein decreased with delayed harvesting stage, considerable variation between stations was observed. The highest protein content was found at Flaten and the lowest at Svanhovd. Correction of crude protein for ammonia-N decreased the percentage by 0.5 units at Tjøtta and Vågønes, and by 0.3 units at Holt, Flaten and Svanhovd.

The crude fibre content was generally higher in silage than in ensiled crops. At Holt, Flaten and Svanhovd the content of crude fibre was lower in the silage from the barley variety Bode than from Lise.

On average the sugar content was lower in silage than in fresh crops, indicating a net use of simple sugars during the ensiling process. At Holt, Flaten and Svanhovd sugar content increased when harvesting was postponed from one week after heading to the dough stage of ripeness.

Levels of organic acids, ammonia and pH in silage are given in Tables 8 and 9. All silages were of good quality, with only traces of butyric, valeric and propionic acids in a few silos. Some very low values of lactic and acetic acids were observed, especially at the Holt and Flaten stations. The values for NH_3-N as a percentage of total-N were generally low, with only three silos exceeding the 8% limit for good silage established by Breirem & Homb (1970). With the exception of two silos, pH values of the silage were below 4.2, which is considered favourable (Breirem & Homb l.c.).

The content of ethanol was analysed in a limited number of silage samples from Vågønes in 1983. The values obtained were 0.12, 0.18 and 0.11% of silage for harvesting stages H1, H2 and H3, respectively.

Table 6. Chemical composition of the silage. LS means, Tjøtta and Vågønes

		In % of DM													True
	DM, %	Crude prot.	Corr. c. prot	True prot.	Crude fibre	Ether extr.	N-free extr.	Ash	Sugar	Ca	P	Mg	K	NO_3-N	protein % of CP
Harvesting stage															
1	18.0[a]	11.5[b]	10.9[b]	6.9[b]	33.5	3.3[b]	44.9[a]	7.4	7.0	0.64	0.26[ab]	0.10	1.74[b]	0.04[b]	61.3[a]
2	20.0[b]	9.4[a]	8.9[a]	6.2[a]	32.2	2.8[a]	48.5[b]	7.7	7.1	0.62	0.25[a]	0.10	1.44[a]	0.02[a]	67.5[b]
3	23.3[c]	8.7[a]	8.3[a]	6.2[a]	32.7	2.4[a]	50.1[b]	7.1	7.4	0.65	0.28[b]	0.10	1.82[b]	0.02[a]	71.4[b]
Station															
Tjøtta	19.2[a]	10.6[b]	10.0[b]	6.4	33.6[b]	2.9	45.9[a]	7.6	5.4[a]	0.76[a]	0.27	0.10	1.75	0.04[a]	61.6[a]
Vågønes	21.6[b]	9.2[a]	8.8[a]	6.5	31.6[a]	2.7	49.6[b]	7.1	8.9[b]	0.52[b]	0.26	0.10	1.58	0.02[b]	71.8[b]
Year															
1982	20.9[b]	9.7[ab]	9.2[a]	6.6	31.4[a]	2.7[a]	49.2[b]	7.6	8.0	0.70[b]	0.26	0.10[ab]	1.69	0.03	70.3[b]
1983	18.1[a]	10.8[b]	10.4[b]	6.7	30.9[a]	3.2[b]	47.6[ab]	7.9	7.2	0.76[b]	0.28	0.11[b]	1.60	0.02	61.9[a]
1984	22.2[b]	9.2[a]	8.6[a]	6.1	35.5[b]	2.6[a]	46.6[a]	6.6	6.2	0.44[a]	0.26	0.08[a]	1.70	0.03	68.0[b]
Variety															
Bode	20.4	9.9	9.3	6.3	32.4	2.6[a]	48.4	7.3	6.4	0.57[a]	0.26	0.09[a]	1.70	0.03	65.8
Lise	20.4	10.0	9.4	6.6	32.8	3.0[b]	47.2	7.5	7.9	0.70[b]	0.27	0.10[b]	1.64	0.03	67.7
Mean	20.4	9.9	9.4	6.5	32.6	2.8	47.8	7.4	7.1	0.64	0.27	0.10	1.67	0.03	66.7
R^2	0.84	0.79	0.81	0.69	0.86	0.83	0.88	0.59	0.69	0.90	0.59	0.88	0.70	0.69	0.85

Table 7. Chemical composition of the silage. LS means, Holt, Flaten and Svanhovd

		In % of DM													True
	DM, %	Crude prot.	Corr. c. prot	True prot.	Crude fibre	Ether extr.	N-free extr.	Ash	Sugar	Ca	P	Mg	K	NO_3-N	protein % of CP
Harvesting stage															
1	17.4[a]	12.4[b]	12.1[b]	8.2[b]	31.7	4.0[b]	43.4[a]	8.8	7.5[a]	0.55[b]	0.24	0.13[b]	1.84	0.09[b]	68.1[a]
2	20.7[b]	9.7[a]	9.3[a]	6.9[a]	30.6	2.9[a]	49.8[b]	7.4	13.7[b]	0.48[a]	0.24	0.12[a]	1.77	0.05[a]	73.1[b]
Station															
Holt	17.8[a]	10.3[b]	9.9[b]	7.4[b]	34.9[b]	3.2[a]	44.5[a]	7.5[a]	11.2[b]	0.55[b]	0.25[b]	0.09[a]	1.52[a]	0.05[b]	73.1[b]
Flaten	17.2[a]	14.1[c]	13.6[c]	8.8[c]	29.9[a]	4.0[b]	42.9[a]	9.5[b]	9.0[a]	0.52[ab]	0.26[b]	0.14[b]	2.12[c]	0.12[c]	63.2[a]
Svanhovd	22.1[b]	8.7[a]	8.5[a]	6.6[a]	28.6[a]	3.1[a]	52.4[b]	7.4[a]	11.5[b]	0.49[a]	0.21[a]	0.15[b]	1.76[b]	0.02[a]	75.5[b]
Year															
1982	17.9[a]	11.9[b]	11.6[b]	8.4[b]	30.9[ab]	3.3[a]	46.2[ab]	8.0[ab]	10.4[ab]	0.51[b]	0.25[b]	0.13[b]	1.78	0.06	72.8
1983	17.8[a]	11.7[b]	11.3[b]	7.9[b]	30.0[a]	3.9[b]	45.7[a]	9.1[b]	8.8[a]	0.61[c]	0.25[b]	0.15[c]	1.88	0.08	69.9
1984	21.5[b]	9.5[a]	9.2[a]	6.5[a]	32.4[b]	3.2[a]	47.9[b]	7.3[a]	12.5[b]	0.43[a]	0.21[a]	0.10[a]	1.75	0.06	70.1
Variety															
Bode	19.2	11.1	10.7	7.6	30.3[a]	3.3[a]	47.2	8.5	10.0	0.53	0.24	0.13	1.79	0.06	70.0
Lise	18.9	11.0	10.7	7.5	31.9[b]	3.6[b]	46.0	7.8	11.2	0.51	0.24	0.12	1.81	0.07	71.2
Mean	19.0	11.0	10.7	7.6	31.1	3.5	46.6	8.1	10.6	0.52	0.24	0.12	1.80	0.07	70.6
R^2	0.92	0.95	0.96	0.93	0.87	0.96	0.95	0.75	0.82	0.89	0.86	0.90	0.87	0.90	0.76

Table 8. The contents of organic acids, ammonia and pH in the silage. LS means, Tjøtta and Vågønes

	Acids in silage, %			NH_3-N,	
	Formic	Acetic	Lactic	% of N	pH
Harvesting stage					
1	0.25	0.25	0.66	4.79	3.97
2	0.27	0.19	0.53	5.20	3.98
3	0.27	0.22	0.75	5.34	4.04
Station					
Tjøtta	0.32[b]	0.23	0.65	5.96[b]	4.01
Vågønes	0.21[a]	0.21	0.64	4.26[a]	3.99
Year					
1982	0.34[b]	0.33[b]	0.71[ab]	4.91[b]	4.00[ab]
1983	0.25[a]	0.15[a]	0.44[a]	3.75[a]	3.90[a]
1984	0.20[a]	0.18[a]	0.78[b]	6.66[c]	4.08[b]
Variety					
Bode	0.28	0.20	0.69	4.85	3.96
Lise	0.24	0.24	0.60	5.36	4.03
Mean	0.26	0.22	0.64	5.11	4.00
R^2	0.77	0.67	0.61	0.78	0.74

Table 9. The contents of organic acids, ammonia and pH in the silage. LS means, Holt, Flaten and Svanhovd

	Acids in silage, %			NH_3-N,	
	Formic	Acetic	Lactic	% of N	pH
Harvesting stage					
1	0.26[a]	0.09[a]	0.20	2.87[a]	3.94
2	0.29[b]	0.14[b]	0.24	3.57[b]	3.94
Station					
Holt	0.27	0.06[a]	0.16[a]	3.40[b]	4.02[b]
Flaten	0.29	0.10[b]	0.19[a]	3.44[b]	3.95[ab]
Svanhovd	0.27	0.19[c]	0.31[b]	2.82[a]	3.86[a]
Year					
1982	0.31[b]	0.13[b]	0.22	2.97	3.94[ab]
1983	0.23[a]	0.06[a]	0.20	3.38	3.89[a]
1984	0.29[b]	0.17[c]	0.25	3.30	3.99[b]
Variety					
Bode	0.26	0.13	0.23	3.24	3.94
Lise	0.29	0.11	0.21	3.20	3.94
Mean	0.28	0.12	0.22	3.22	3.94
R^2	0.71	0.94	0.81	0.67	0.62

Table 10. Chemical composition of the effluent, amount of effluent and effluent loss of nutrients. LS means, Tjøtta and Vågønes

	DM, %	In % of DM: Crude protein	In % of DM: Ash	Effluent, kg (100 kg)[1] ensiled crops	Effluent loss of nutrients, %: DM	Organic matter	Crude protein
Harvesting stage							
1	4.1	23.2[b]	24.6[ab]	29.0[c]	7.7[c]	6.3[c]	13.5[c]
2	4.8	17.7[a]	22.7[a]	20.9[b]	5.2[b]	4.4[b]	9.2[b]
3	5.3	16.7[a]	26.0[b]	4.6[a]	1.0[a]	0.8[a]	2.1[a]
Station							
Tjøtta	4.1[a]	25.4[a]	30.3[a]	20.3	5.0	3.8	11.5[b]
Vågønes	5.3[b]	13.0[b]	18.5[b]	16.0	4.3	3.8	5.0[a]
Year							
1982	5.5[b]	17.5[a]	23.3	15.4	3.8[a]	3.1[a]	6.3
1983	4.4[a]	16.1[a]	23.9	22.1	6.0[b]	5.1[b]	8.1
1984	4.2[a]	24.0[b]	26.1	17.1	4.1[ab]	3.2[a]	10.3
Variety							
Bode	4.5	19.1	24.7	19.0	4.9	4.0	8.1
Lise	4.9	19.3	24.2	17.4	4.4	3.6	8.4
Mean	4.5	20.1	24.6	18.2	4.6	3.8	8.2
R^2	0.79	0.93	0.96	0.77	0.79	0.79	0.80

Table 11. Chemical composition of the effluent, amount of effluent and effluent loss of nutrients. LS means, Holt, Flaten and Svanhovd

	DM, %	In % of DM: Crude protein	In % of DM: Ash	Effluent, kg (100 kg)[1] ensiled crops	Effluent loss of nutrients, %: DM	Organic matter	Crude protein
Harvesting stage							
1	4.5[a]	20.9[b]	25.5[b]	35.7[b]	10.4[b]	8.5[b]	14.9[b]
2	7.0[b]	14.2[a]	17.5[a]	20.3[a]	6.7[a]	6.0[a]	9.9[a]
Station							
Holt	4.4[a]	17.8[b]	20.6[b]	34.8[b]	10.3[b]	8.8[c]	15.0[b]
Flaten	4.6[a]	23.7[c]	27.8[c]	31.6[b]	9.1[b]	7.3[b]	14.3[b]
Svanhovd	8.1[b]	11.2[a]	16.1[a]	17.6[a]	6.3[a]	5.6[a]	8.0[a]
Year							
1982	5.0[a]	17.9	23.1	28.1[b]	8.5[ab]	6.9[a]	12.9
1983	5.5[a]	18.7	20.6	31.8[b]	9.8[b]	8.4[b]	13.1
1984	6.7[b]	16.0	20.8	24.0[a]	7.4[a]	6.3[a]	11.2
Variety							
Bode	5.9	17.2	20.9	28.6	8.6	7.3	12.5
Lise	5.6	17.9	22.1	27.3	8.5	7.2	12.3
Mean	5.6	18.3	21.9	28.0	8.1	7.2	12.1
R^2	0.92	0.86	0.88	0.96	0.95	0.90	0.96

D. Effluent losses

During ensiling nutrients are normally lost as effluent, as gases resulting from fermentation, and as waste caused by moulding of the silage. In these experiments there was no waste attributable to mould fungi.

The chemical compositions of effluent and effluent losses are given in Tables 10 and 11. In several cases with crops harvested at the H3 stage, and in some cases at H2, no effluent was recorded.

DM content of the effluent increased with harvesting stage, but these differences were not significant. The crude protein content in the effluent was highest at H1.

The amount of effluent varied greatly among treatments, with harvesting stage as the main source of variation. Losses of nutrients decreased sharply with increasing crop age. Harvesting at the yellow ripeness stage gave almost no effluent losses. No differences between barley varieties were found either for chemical composition of effluent or in losses of nutrients.

Because there was a high degree of experimental error when weighing the silage, figures for total losses are not presented. According to McDonald (1981) fermentation losses will be about 2-5% of DM, but with much lower energy losses.

E. Digestibility of the silage

Tables 12 and 13 show the digestion coefficients for the different components of the silage. Calculation of the digestibility of crude protein was based on the content of corrected crude protein in the silage.

Digestibility of DM, organic matter, crude protein and crude fibre decreased significantly as harvesting was delayed. Also the digestibility of ether extract and N-free extract decreased as the crop matured, although not significantly in all cases. No significant differences in digestibility were observed between the varieties Bode and Lise. The digestibility of organic matter within stations and years is shown in Figure 1.

Table 12. Digestibility coefficients of the silage. LS means, Tjøtta and Vågønes

	DM	Organic matter	Crude protein	Ether extract	N-free extract	Crude fibre	Ash
Harvesting stage							
1	70.7^{c}	72.6^{c}	66.4^{c}	70.2	72.2^{b}	75.9^{c}	46.1^{b}
2	64.5^{b}	66.6^{b}	58.8^{b}	69.1	69.8^{b}	63.1^{b}	39.9^{ab}
3	59.8^{a}	61.6^{a}	49.6^{a}	66.3	65.7^{a}	57.0^{a}	33.5^{a}
Station							
Tjøtta	64.9	66.3	61.9^{a}	69.9	67.9^{a}	64.6	47.0^{b}
Vågønes	65.0	67.5	54.7^{b}	67.2	70.5^{b}	65.4	32.6^{a}
Year							
1982	65.9	67.5	55.8	62.4^{a}	70.2	66.0	46.6^{b}
1983	65.4	67.6	61.4	73.0^{b}	69.4	65.9	40.2^{ab}
1984	63.6	65.7	57.7	70.2^{b}	68.1	63.0	32.7^{a}
Variety							
Bode	64.9	67.0	58.1	66.5	69.7	64.8	36.7
Lise	65.0	66.8	58.5	70.6	68.7	65.1	43.0
Mean	65.0	66.9	58.3	68.5	69.2	65.0	39.8
R^2	0.80	0.81	0.80	0.71	0.68	0.86	0.76

Table 13. Digestibility coefficients of the silage. LS means, Holt, Flaten and Svanhovd

	DM	Organic matter	Crude protein	Ether extract	N-free extract	Crude fibre	Ash
Harvesting stage							
1	72.1[b]	75.1[b]	68.9[b]	74.5[b]	73.8	78.0[b]	42.5
2	68.4[a]	70.3[a]	61.6[a]	69.7[a]	73.5	66.5[a]	43.8
Station							
Holt	68.4[a]	70.4[a]	64.4[b]	71.1[a]	70.3[a]	71.6[a]	43.5
Flaten	68.8[a]	71.9[a]	72.4[c]	75.2[b]	71.8[a]	70.2[a]	42.1
Svanhovd	73.5[b]	75.8[b]	58.9[a]	70.2[a]	78.8[b]	75.0[b]	43.9
Year							
1982	69.0[a]	71.4[a]	65.1	68.5[a]	72.7[a]	70.5	40.6
1983	68.8[a]	71.8[a]	66.2	75.2[b]	72.3[a]	71.4	41.7
1984	72.9[b]	75.0[b]	64.4	72.8[b]	76.0[b]	74.8	47.3
Variety							
Bode	70.4	73.2	64.7	71.3	74.4	73.0	41.3
Lise	70.0	72.2	65.8	73.0	72.9	71.5	45.1
Mean	70.2	72.7	65.2	72.1	73.6	72.2	43.2
R^2	0.84	0.87	0.90	0.76	0.88	0.92	0.59

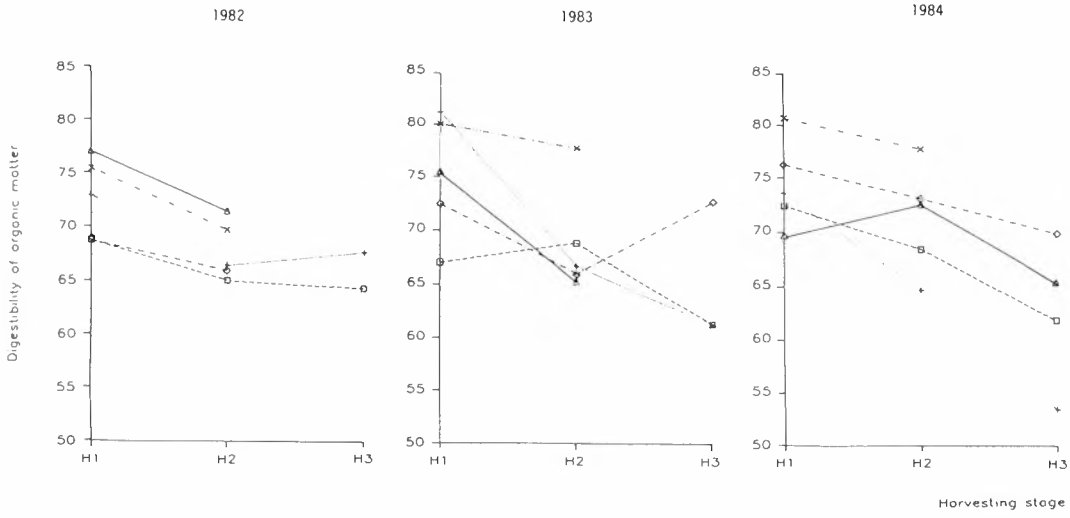

Figure 1. Digestibility of organic matter in silage, means of the two cultivars, Bode and Lise.

o------o Tjøtta, • • Vågønes, o- - - -o Holt, Δ——Δ Flaten, × - - - × Svanhovd

Table 14. Fattening feed units (FU), digestible crude protein (DCP) and metabolizable energy (ME) (kg DM) [1] in the silage. LS means, Tjøtta and Vågønes

	FU			
	Value number 80	Fibre deduction	DCP, g	ME, MJ
Harvesting stage				
1	0.765[c]	0.746[c]	73[c]	10.5[c]
2	0.700[b]	0.673[b]	54[b]	9.6[b]
3	0.650[a]	0.610[a]	42[a]	8.9[a]
Station				
Tjøtta	0.697	0.660	62[b]	9.6
Vågønes	0.713	0.692	51[a]	9.7
Year				
1982	0.710	0.690	53[a]	9.7
1983	0.708	0.690	65[b]	9.7
1984	0.697	0.648	51[a]	9.5
Variety				
Bode	0.707	0.679	55	9.7
Lise	0.704	0.673	57	9.6
Mean	0.705	0.676	56	9.6
R^2	0.78	0.78	0.81	0.79

Table 15. Fattening feed units (FU), digestible crude protein (DCP) and metabolizable energy (ME) (kg DM) [1] in the silage. LS means, Holt, Flaten and Svanhovd

	FU			
	Value number 80	Fibre deduction	DCP, g	ME, MJ
Harvesting stage				
1	0.779[b]	0.774[b]	85[b]	10.8[b]
2	0.741[a]	0.734[a]	60[a]	10.1[a]
Station				
Holt	0.741	0.707[a]	65[b]	10.2[a]
Flaten	0.738	0.734[a]	101[c]	10.3[a]
Svanhovd	0.801	0.821[b]	52[a]	10.9[b]
Year				
1982	0.747[a]	0.739[a]	79[b]	10.3[a]
1983	0.741[a]	0.737[a]	77[b]	10.3[a]
1984	0.792[b]	0.786[b]	61[a]	10.8[b]
Variety				
Bode	0.763	0.762	72	10.5
Lise	0.757	0.746	73	10.4
Mean	0.760	0.754	72	10.5
R^2	0.88	0.89	0.95	0.87

F. Energy value and digestible crude protein content of the silage

As mentioned previously, the content of FU was computed in two different ways, using a value number of 80 and using a crude fibre deduction of 1.04 as recommended by Presthegge (1959). The FU contents are presented in Tables 14 and 15, which also show the metabolizable energy (ME) and digestible crude protein (DCP) contents.

At Tjøtta, Vågønes and Holt the FU values estimated by means of the fibre deduction method gave lower values than the value number 80 method. At Flaten the two methods gave almost the same results, while at Svanhovd the value number 80 method gave the highest values. These differences reflected the content of crude fibre in the silage.

The energy value of the silage, regardless of method of calculation, was significantly decreased when the harvesting stage was postponed. With an equivalent harvesting stage, FU content was higher at the three northernmost stations than at the two southernmost stations. Significant interactions between harvesting stage and station were found at Tjøtta and Vågønes, and between harvesting stage and year at Holt, Flaten and Svanhovd.

The content of DCP was low, and decreased significantly with postponed harvesting stage. Considerable differences were found between stations, the content of DCP being highest at Flaten and lowest at Svanhovd. The content of ME correlated well with the calculated net energy (FU) values.

DISCUSSION

A. Crop yield, botanical and morphological composition

The DM yield of barley and fodder rape mixtures has been found to increase until the yellow ripeness stage (Hagsand 1977, Østgård 1980, Volden unpublished). In the present experiment the DM yield increased from H1 to H2, but not from H2 to H3. The lack of change from H2 to H3 may be explained by the low ratio of rape in the present experiment, since barley plants have a low growth rate at this stage of maturity (Garmo 1984).

Although the ratio of fodder rape in the crop mixture was somewhat lower than thought necessary to produce a silage with good keeping qualities, only minor problems with aerobic deterioration of the silage were observed in full scale trials (Nordang 1990a, b). Field trials have shown that smaller amounts of barley seed, or more widely spaced barley rows produce crop mixtures with a higher fodder rape content (Wingan 1986, Volden unpublished).

B. Chemical characteristics of fresh crops and silage

Since the harvested crops constituted uneven mixtures of the two contrasting species, grown under marginal climatic conditions, considerable variation in the chemical composition of the silages was observed. Year and site contributed to much of this variation, with significant interaction between year and station for many parameters. Generally, minor differences between the two barley varieties were observed, whereas the different harvesting stages produced greater differences in some properties of the crop and the silage.

Generally, a good relationship between the chemical composition of freshly cut crops and silage was found. The observed differences reflect the silage fermentation and the decreasing amount of effluent loss through postponement of harvesting time. The effluent contained more crude protein and ash, and less crude fibre than the fresh crops, and this led to the difference between fresh crops and silage.

The DM content at the early harvesting stage was low, but increased rapidly with increasing crop age. However, the low DM content in the early harvested crop did not seem to influence the

pattern of fermentation adversely. The difference in DM content between harvesting stages was maintained from freshly cut crop to silage, though its magnitude was reduced. The reduction reflected the sharp decrease in effluent produced from the first to the last harvesting stages.

The content of crude protein decreased from an acceptable level at H1 to a low level at H2 and H3. It also decreased with ensiling. This reduction decreased with age of the crop, indicating that a diminished crude protein loss was achieved by postponing the harvesting time. Although similar amounts of N fertilizer were applied, significant differences in content of crude protein and digestible crude protein between research stations were probably due to local soil and weather conditions.

Compared with other reports concerning barley-rape mixtures, the content of crude fibre was high (Hagsand 1977, Lunnan 1983, Pestalozzi unpublished). This was also the case with whole crop barley (Garmo 1984). The content of crude fibre in DM was higher in the silage than in the corresponding fresh crops, because of a lower effluent loss of crude fibre compared with the other constituents.

Concerning the minerals, the content of Ca was slightly higher than found in the dominant grass species, timothy, at the same research stations (Hole 1985). The contents of Mg, P and K were slightly lower than in timothy.

All the silages were well conserved. Some indication of a lower degree of fermentation in the three northernmost stations compared with the southernmost ones, with lower contents of lactic and acetic acids and lower ammonia-N, may be explained by the more rapid decrease in the environmental temperature in the north during the autumn (Table 1).

High effluent production during ensiling causes high losses of DM and may create disposal problems. An important finding, therefore, is the sharp decrease in effluent loss by postponed harvesting time, which is a result of the higher DM content in the crop mixture (McDonald 1981).

C. Digestibility and energy value

Results from a pilot study with barley-fodder rape silage showed only a minor decrease in digestibility with advancing maturity (Hole 1982). This concurs with Danish experiments with whole crop barley (Hostrup 1976, Thomsen 1977, Kristensen et al. 1979).

In the present experiment a clear decrease in digestibility as a result of delayed harvesting was shown in almost every year-station combination, although extensive variation was shown between years and site. The pattern of digestibility, however, was in accordance with results from southern Norway (Lunnan 1983, Pestalozzi unpublished) and Norwegian experiments with whole crop barley (Garmo 1982).

When compared at a similar level of maturity, digestibility was higher at the three northernmost stations than at the southernmost stations, despite a lower ear to stem ratio. This indicates a difference in plant development, which is supported by lower crude fibre and higher sugar content in the north.

Compared to grass silage, the digestibility of crude fibre was lower, while that of nitrogen-free extract (NFE) was higher (Hole 1985, Bergheim 1979). The energy content of barley-rape silage is low at the last harvesting, the FU content being at a similar level to that found in grass silage from timothy harvested about four weeks after heading (Hole 1985).

The yield of silage net energy was calculated from the yield of DM, the effluent DM losses and the concentration of net energy (FU calculated using value number 80). At Tjøtta and Vågønes the net FU yields were 3600, 4650 and 4500 FU ha^{-1}, at H1, H2 and H3, respectively, and at Flaten and Svanhovd 2650 and

4500 FU ha^{-1} at I11 and I12, respectively. It should, however, be remembered that other experiments have shown increases in DM yield until yellow ripeness of barley (Østgård 1980, Volden unpublished).

From this experiment it can be concluded that barley-fodder rape mixture is well suited to ensiling from heading until the yellow ripening stage of barley. Harvesting at the dough ripening stage of barley combines a high-yielding level with an acceptable energy concentration.

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Barley-fodder rape silage

II. Feeding experiments with bulls

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The feeding potential of silage made from a mixed crop of barley and fodder rape and harvested at different stages was evaluated in four feeding experiments with a total of 76 fattening bulls. Three of the experiments were conducted with three harvesting stages (one week after heading of barley (H1), dough ripening (H2) and yellow ripening (H3)) and two levels of concentrate supplement (1.5 and 3.0 kg). In the fourth experiment the first harvesting stage was omitted. All silages had good preservation quality. The mean energy concentrations (three experiments) were 0.752, 0.681 and 0.628 feed units (kg dry matter)$^{-1}$ at H1, H2 and H3, respectively. Intake of silage dry matter (DM) and average liveweight gain did not differ significantly between harvesting stages. Net energy concentration estimated from the bulls' energy requirements increased with harvesting stage: 0.685, 0.719 and 0.721 feed units (kg DM)$^{-1}$, respectively. This indicates that the utilization of digestible organic matter decreased with delayed harvesting stage, while the yield of net energy increased until yellow ripening of barley.

Key words: Whole barley, fodder rape, silage, fattening bulls, liveweight gain, silage intake, feed utilization.

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The nutritive value of silage made from a mixed crop of barley and fodder rape has been discussed by Nordang (1990a) on the basis of ensiling and digestibility trials. This paper details further investigations in which fattening bulls were used to determine the feeding potential of silage made from barley-rape mixtures harvested at three different ripeness stages of barley.

These experiments form part of the experimental series «The use of barley-fodder rape silage for cattle and sheep in Northern Norway», and were carried out at Vågønes Research Station, Bodø.

This publication is the second in a series of three (Nordang 1990a, b). Utilization of this type of silage by dairy cows is discussed in Part III.

MATERIALS AND METHODS

A. Plan of experiments

During the period 1981-84 four nutrition trials (designated I-IV, Table 1) were conducted using growing bulls. A randomized block design with a 3 x 2 factorial arrangement of treatments (three harvesting stages of silage and two levels of concentrate) was used on three occasions (Experiments I, III and IV). The three harvesting stages were as follows:

1. Silage made from barley and fodder rape harvested one week after heading of barley
2. Silage made from barley and fodder rape harvested at dough ripening stage of barley
3. Silage made from barley and fodder rape harvested at yellow ripening stage of barley

In addition to silage, offered *ad libitum* the animals within each harvesting stage were given concentrate at one of two levels:

A. 1.5 kg concentrate animal^{-1} day^{-1}
B. 3.0 kg concentrate animal^{-1} day^{-1}

The bulls were allotted to four blocks by weight and one animal from each group was then allotted to each of the treatments. Experiment II was conducted using a simpler design because of reduced crop yields in 1982 following an extremely wet spring. Only silage from the second and third harvestings was used, and all animals received 2.25 kg concentrate animal^{-1} day^{-1}.

The number of bulls in the experiments, the duration of the experimental periods and the mean initial liveweights are given in Table 1.

B. Management of fields and botanical composition

The climatic conditions at Vågønes are typically maritime, with an annual precipitation of 1042 mm and a mean temperature in July of 13.6°C. While the weather conditions in 1981 were about normal, the other three summers were wet and cold (Nordang 1990a). Low temperature combined with heavy rainfall resulted in unfavourable growing conditions and caused problems in harvesting the crops.

The method used for establishing the barley-rape mixture is described by Nordang (1990a). Nitrogen was applied at a rate of 100-120 kg ha^{-1} as a combination of inorganic fertilizer and cattle slurry before sowing. The application of K was 50 kg ha^{-1} and of P 140 kg ha^{-1}.

The crops were harvested using a forage flail harvester with the addition of formic acid (85%) at a rate of 3 l ton^{-1} of crop. They were ensiled in experimental tower silos (diameter = 3.0 m, height = 6.0 m) and a two-layer plastic sheet was used to cover the crops before 500 kg m^{-2} pressure was applied. The botanical composition, dry matter (DM) yield and dates of harvest for the crops are given in Table 2.

Germination problems in fodder rape caused by dry spring weather resulted in the ratio of fodder rape in the mixed crop being very low in Experiment I. In Experiment II the fodder rape content was 30% of DM at the dough stage of barley, increasing to 48% by the yellow ripening stage. This was due to a rather thin plant stand of barley which allowed intensive growth of rape that year. In Experiment III the ratio of rape varied between fields, producing undesirable differences in botanical composition between the harvesting stages. In Experiment IV the rape content increased markedly from the second harvesting to the third harvesting, as observed in other experiments (Nordang 1990a).

Table 1. Number of bulls, duration of experiments and average initial liveweight

Experiment	No. of bulls	Days in experiment	Average liveweight
I	17	87	390
II	12	56	352
III	24	82	315
IV	23	107	346

Table 2. Botanical composition, dry matter (DM) yield and dates of harvesting of the crop

Experiment	Years	Harvesting stage	% of sample DM			DM yield ton ha^{-1}	Dates of harvest
			Barley	Fodder rape	Weeds		
Experiment I	1981-82	1	89	6	5	-	22.7.
		2	94	3	3	-	17.8.
		3	94	5	1	-	7.9.
Experiment II	1982-83	2	58	30	12	7.7	23.8.
		3	42	48	10	7.0	21.9.
Experiment III	1983-84	1	75	16	9	4.1	19.-20.7.
		2	90	7	3	5.5	15.8.
		3	60	27	13	6.4	15.9.
Experiment IV	1984-85	1	72	16	12	4.4	23.-24.7.
		2	80	15	5	8.4	20.-21.8.
		3	70	27	3	9.4	10.-11.9.

C. Livestock and management

Yearling bulls of the NRF breed were used in all experiments. During summer, prior to each trial, the bulls were maintained on pasture until the end of September when they were housed. The experiments started in December or in the first half of January. The bulls were stall-fed with both silage and concentrate on an individual basis throughout the experiments. Silage was offered twice daily in quantities calculated to be about 10% in excess of consumption.

At the beginning and end of the experiments the live-weight of each bull was recorded on two consecutive days. During the experimental periods the bulls were weighed once every four week. Three times during Experiments II, III and IV rumen samples were taken using a stomach tube about three hours after feeding in the morning.

At slaughter, carcass weights and quality grade, weights of liver and kidney fat, conformation score, amount of fat and fat colour were recorded.

D. Feed sampling

DM content in silage was determined weekly. Every second week samples from silage and silage refusals were taken for other chemical analyses. Samples of the concentrates offered were collected weekly during each of the experiments. Digestibility coefficients of the silages were determined with sheep fed at maintenance level (two wethers per silage).

E. Chemical analysis and calculation of nutritive value

Chemical analyses of the crop ensiled, silage and concentrate were carried out at the Chemical Laboratory at Holt Research Station. The methods are described more fully by Nordang (1990a).

Silage DM was corrected for losses of volatile substances according to Ekern (1972), assuming that 80% of the formic, acetic, butyric, propionic and valeric acids are lost during oven drying at 105°C.

Estimates of energy values of the silage were based on data from chemical analysis and the coefficients of digestibility as described by Nordang (1990a).

The net energy content was also estimated from the weight gain of the bulls, as described by Saue et al. (1978), assuming that 1 kg corrected liveweight gain requires 2.5 feed units (FU) and the maintenance requirement is 3.78 FU (100 kg metabolic weight)$^{-1}$.

For the concentrates, the net energy content given by the producer was used in the computations.

F. Statistical analysis

The statistical analysis was carried out using the General Linear Models procedure described by SAS (1985). The following model was used:

$$Y_{ijl} = \mu + a_i + b_j + (ab)_{ij} + k_l + e_{ijl}$$

where

Y_{ijl} = the parameter analysed
μ = general mean
a_i = the effect of i-th harvesting stage
b_j = the effect of j-th concentrate level
$(ab)_{ij}$ = the interaction between i-th harvesting stage and j-th concentrate level
k_l = the effect of l-th block
e_{ijl} = random error

Non-significant interactions were pooled into the error term. Least square means (LS means) were analysed using multiple t-tests and those with different superscripts indicate a significant difference ($P < 0.05$).

Experiments I and IV were calculated as imbalanced factorial designs using LS means (SAS 1985) as a result of cattle being withdrawn from the trial.

RESULTS

A. Animal health

In Experiment I one bull in treatment 1A suffered from a foreign body in the reticulo-rumen and had to be excluded from the experiment. In Experiment IV one bull in treatment 2A had to be slaughtered three weeks into the experiment because of infection of the prepuce. Apart from this, animal health in the experiments was good.

B. Chemical composition

The chemical composition of the silage is given in Table 3. The DM content of the silage was lower at the first maturity stage than at the other two stages. The differences in DM percentage between harvesting stages were less for silage than for freshly cut crops, indicating higher effluent loss by the H1 stage. The crude protein content was low in all silages every year. True protein as a percentage of crude protein was lowest for the first harvesting stage in all three years of representation.

In Experiments I and IV the content of crude fibre was high at the H1 stage,

Table 3. Chemical composition of the silages

Harvesting stage	Experiment I			Experiment II		Experiment III			Experiment IV		
	1	2	3	2	3	1	2	3	1	2	3
DM, percentage	20.0	22.2	22.5	22.8	21.1	19.7	21.3	23.2	18.3	23.7	23.7
% of DM:											
Crude protein	9.9	9.0	8.3	9.4	11.5	10.5	10.1	9.5	10.8	8.1	10.2
Corrected crude protein	9.3	8.3	7.8	9.0	10.9	9.6	9.5	8.8	10.3	7.7	9.5
True protein	5.6	5.3	5.4	7.4	8.3	6.8	6.8	6.7	6.0	5.5	6.2
Ether extract	3.3	2.7	2.1	3.7	3.6	2.9	2.3	2.1	3.3	2.9	2.5
N-free extract	44.5	48.3	52.8	49.8	47.9	45.5	49.1	48.9	44.3	53.3	53.3
Crude fibre	34.2	31.7	30.7	30.2	32.0	32.6	33.8	33.0	36.1	30.5	27.6
Ash	8.7	9.0	6.6	7.3	5.6	9.4	5.3	7.2	6.0	5.6	7.1
Sugar	2.5	2.7	3.1	8.5	3.2	2.5	3.7	3.5	7.0	7.3	5.0
Ca	0.42	0.37	0.27	0.92	1.17	1.21	0.44	0.34	0.51	0.60	0.85
P	0.23	0.24	0.21	0.23	0.28	0.25	0.26	0.29	0.22	0.25	0.27
Mg	0.11	0.11	0.10	0.10	0.10	0.11	0.08	0.10	0.06	0.08	0.10
K	1.86	1.83	0.97	1.05	0.94	1.54	1.13	1.49	1.46	1.35	1.54
NO_3-N	0.02	0.01	0.01	0.03	0.11	0.04	0.03	0.04	0.02	0.03	0.03
True protein in % of crude protein	55.9	58.8	65.4	79.4	72.3	64.2	68.8	71.1	56.0	67.0	60.3

and decreased with postponed harvesting. In Experiment II the crude fibre content increased from H2 to H3, while it remained stable in Experiment III.

The content of N-free extract in silage harvested one week after heading was lower than that by later harvesting. Ash content varied from 5.3 to 9.4% of DM. The content of Ca was high in Experiment II and in the first harvest of Experiment III, while the content of K was generally low. The sugar content in silage varied extensively from 2.5 to 8.5% of DM. The fermentation characteristics (Table 4) indicated a good preservation of the silage (Breirem & Homb 1970).

The pH value was low in all silages, although lactic acid content showed some variation. In Experiment III silage from the H1 stage had a higher content of butyric and propionic acid than the other silages. This was caused by two silage samples in which the butyric acid contents were 0.26 and 0.24%, while the propionic acid content was 0.25. The other samples were of good quality.

The content of ethanol was analysed in a limited number of silage samples from Experiments II and III. The values obtained were 0.08, 0.20 and 0.16% of silage at harvesting stages 1, 2 and 3, respectively.

C. Digestibility and nutritive value

The digestibilities of organic matter markedly decreased with advancing crop maturity in Experiments I and III, whereas in Experiments II and IV this decrease was considerably less (Table 5). Crude fibre digestibility decreased at a faster rate than the digestibility of any of the other nutrients.

The contents of FU, metabolizable energy (ME) and digestible crude protein (DCP) (kg silage DM)$^{-1}$ are presented in Table 6. These values are based on the

Table 4. Ammonia, pH and content of organic acids in the silages

	Experiment I			Experiment II		Experiment III			Experiment IV		
Harvesting stage	1	2	3	2	3	1	2	3	1	2	3
NH_3-N in % of total N	6.9	8.4	6.4	4.8	5.6	5.5	3.8	7.4	7.5	7.8	3.9
pH	4.0	3.9	4.0	3.8	3.9	4.2	3.8	4.0	3.9	3.8	4.1
In silage, %:											
Formic acid	0.07	0.07	0.10	0.30	0.14	0.18	0.13	0.25	0.24	0.25	0.15
Acetic acid	0.51	0.57	0.39	0.28	0.25	0.48	0.37	0.31	0.31	0.33	0.44
Propionic acid	0.00	0.02	0.00	0.00	0.00	0.08	0.01	0.05	0.01	0.00	0.02
Butyric acid	0.00	0.03	0.00	0.00	0.00	0.08	0.01	0.02	0.02	0.04	0.02
Valeric acid	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Lactic acid	1.16	1.45	0.74	0.56	0.56	1.20	1.09	0.66	0.56	0.79	1.03

Table 5. Digestion coefficients of the silages

	Experiment I			Experiment II		Experiment III			Experiment IV		
Harvesting stage	1	2	3	2	3	1	2	3	1	2	3
Dry matter	68.4	64.8	60.0	65.6	66.2	72.2	55.0	51.9	64.6	64.7	64.5
Organic matter	71.6	68.0	61.8	69.1	68.1	76.4	57.0	53.1	68.1	67.1	66.6
Crude protein	58.8	48.5	48.0	52.1	64.2	62.2	57.6	56.2	68.4	65.5	67.7
Ether extract	80.5	50.8	67.9	71.5	70.7	80.3	67.0	68.0	77.0	77.0	73.5
N-free extract	69.8	71.4	60.4	72.9	71.3	76.6	59.0	56.8	68.2	69.1	70.7
Crude fibre	76.0	67.5	57.2	68.6	64.2	80.1	52.9	45.2	67.0	63.0	58.1
Ash	29.1	31.1	54.8	18.0	38.4	22.1	27.2	41.5	12.1	40.6	36.7

chemical composition of silage samples (Table 3) and coefficients of digestibility obtained with sheep (Table 5).

According to the recorded digestibilities, energy content of the silage decreased markedly in Experiments I and III, whereas in Experiments II and IV no decrease in energy content was found with later harvesting dates. Calculation by value number 80 generally resulted in higher FU values than by using the fibre deduction 1.04 NK_F (g fibre)$^{-1}$. In all the experiments the content of DCP was low at all harvesting stages. The chemical composition of the concentrate is shown in Table 7. The main protein sources in the concentrate were rapeseed meal and soya bean meal.

D. Feed intake

In the first experiment the bulls on the H1 stage consumed the highest quantities of forage DM, and also had greater intakes of forage DM (100 kg liveweight)$^{-1}$ and of forage FU than the bulls on H2 and H3 stages (Table 8). Bulls on the H2 stage had a slightly lower intake of DM than bulls on the H3 stage, but their intake of FU was higher.

In Experiment II the bulls in group 2 had an insignificantly higher intake of forage DM and FU than group 3 bulls, but their total FU intake was significantly higher.

In Experiment III forage DM intake was highest in group 1 and lowest in group 3 (Table 9). This difference was nearly significant (P = 0.07). A clear de-

Table 6. Fattening feed units (FU), digestible crude protein (g DCP) and metabolizable energy (MJ ME) kg^{-1} DM in silages

	Experiment I			Experiment II		Experiment III			Experiment IV		
Harvesting stage	1	2	3	2	3	1	2	3	1	2	3
FU calculated using:											
Value number 80	0.741	0.698	0.623	0.714	0.732	0.787	0.614	0.558	0.729	0.730	0.705
Fibre deduction	0.709	0.671	0.586	0.727	0.734	0.775	0.556	0.491	0.683	0.720	0.708
ME, MJ	10.14	9.45	8.46	10.03	10.08	10.76	8.41	7.64	10.04	9.97	9.68
DCP, g	54.6	40.6	37.3	46.8	69.7	60.5	53.8	48.4	70.7	50.2	64.5

Table 7. Chemical composition of the concentrate

	Experiment I	Experiment II	Experiment III	Experiment IV
DM, %	86.9	86.9	86.8	87.6
% of DM:				
Crude protein	17.3	17.2	17.6	19.5
Ether extract	5.0	5.5	6.3	5.1
N-free extract	66.4	64.3	61.4	63.6
Crude fibre	5.9	7.4	8.8	7.1
Ash	5.4	5.6	5.9	4.7
Ca[1)]	0.7	0.7	0.7	0.7
P[1)]	0.6	0.6	0.6	0.6
Na[1)]	0.3	0.3	0.3	0.3
Per kg DM:				
FU[1)]	1.09	1.08	1.08	1.07
g DCP[1)]	144	144	144	143

[1)] Given by the producer

Table 8. Feed intake in Experiments I and II

	Experiment I					Experiment II	
	Harvesting stage			Concentrate		Harvesting stage	
	1	2	3	A	B	2	3
Total no. of animals	5	6	6	8	9	6	6
Forage intake:							
DM intake, kg animal $^{-1}$ day $^{-1}$	6.01^{b}	5.07^{a}	5.31^{a}	5.78^{b}	5.14^{a}	6.01	5.73
DM intake, kg (100 kg liveweight) $^{-1}$	1.40^{b}	1.19^{a}	1.23^{a}	1.37^{b}	1.17^{a}	1.53	1.47
Intake of FU animal $^{-1}$ day $^{-1}$	4.45^{b}	3.55^{a}	3.31^{a}	3.99^{b}	3.54^{a}	4.40	4.13
Total feeds:							
Intake of FU animal $^{-1}$ day $^{-1}$	6.56^{b}	5.65^{a}	5.41^{a}	5.43^{a}	6.32^{b}	6.52^{b}	6.22^{a}
DCP, g (kg DM) $^{-1}$	76.5^{b}	68.6^{a}	66.3^{a}	63.1^{a}	77.8^{b}	71.6^{a}	90.6^{b}
DCP, g FU $^{-1}$	92.3^{c}	85.2^{a}	88.3^{b}	82.6^{a}	94.6^{b}	87.5^{a}	111.7^{b}

Table 9. Feed intake in Experiments III and IV

	Experiment III					Experiment IV				
	Harvesting stage			Concentrate		Harvesting stage			Concentrate	
	1	2	3	A	B	1	2	3	A	B
Total no. of animals	8	8	8	12	12	8	7	8	11	12
Forage intake										
DM intake, kg animal $^{-1}$ day $^{-1}$	5.53	5.16	4.95	5.62^{b}	4.80^{a}	5.58	6.31	6.27	6.48^{b}	5.62^{a}
DM intake, kg (100 kg liveweight) $^{-1}$	1.50^{b}	1.37^{ab}	1.33^{a}	1.53^{b}	1.27^{a}	1.37^{a}	1.55^{b}	1.51^{ab}	1.61^{b}	1.35^{a}
Intake of FU animal $^{-1}$ day $^{-1}$	4.35^{b}	3.16^{a}	2.76^{a}	3.68^{b}	3.17^{a}	4.07	4.47	4.43	4.63^{b}	4.02^{a}
Total feeds:										
Intake of FU animal $^{-1}$ day $^{-1}$	6.46^{b}	5.27^{a}	4.88^{a}	5.09^{a}	5.99^{b}	6.18	6.58	6.55	6.04^{a}	6.84^{b}
DCP, g (kg DM) $^{-1}$	80^{b}	80^{b}	76^{a}	71^{a}	86^{b}	91^{c}	74^{a}	81^{b}	76^{a}	89^{b}
DCP, g FU $^{-1}$	93^{a}	108^{b}	107^{b}	98^{a}	107^{b}	111^{c}	93^{a}	102^{b}	98^{a}	106^{b}

crease in daily intake of forage FU and total FU was observed when the harvesting stage was postponed. In Experiment IV, group 1 bulls had the lowest forage DM and the lowest forage FU intakes.

Increasing the level of concentrate from 1.5 to 3.0 kg caused a significant depression in forage intake, although there was an increase in total FU intake. Increased concentrate allocation resulted in a reduction in silage intake by 0.43 kg DM (kg concentrate)$^{-1}$ in Experiment I, 0.55 in Experiment III and 0.57 in Experiment IV. No significant interaction between harvesting stage and concentrate level was observed.

The content of DCP in total rations was low in several cases (Tables 8 and 9). For bulls on the low level of concentrate and silage with low protein content, the total protein concentration in the ration was also low. In the different subgroups crude protein as a percentage of ration DM was:

	1A	1B	2A	2B	3A	3B
Experiment I	11.6	12.7	12.2	12.8	10.4	12.4
Experiment II			11.9		13.7	
Experiment III	12.3	13.7	12.0	13.7	11.5	13.5
Experiment IV	12.9	14.7	10.5	12.4	12.2	14.0

E. Animal performance

Liveweights and liveweight gains are given in Tables 10 and 11. Corrected liveweight gain estimated from carcass weight gave a dressing percentage of 50. Carcass weight was estimated as 98% of warm carcasses.

In Experiment I the average corrected daily gain was low (965 g). The bulls fed silage from the intermediate harvesting stage had the lowest daily gain, corrected and uncorrected. The bulls offered the early harvested silage had both the highest daily liveweight gain and corrected daily liveweight gain (Table 10).

In Experiment II all bulls showed a high corrected daily liveweight gain, averaging 1366 g d^{-1}. However, since this experiment was of short duration, only 56 days, the figures for liveweight gain are less reliable than those from the other experiments. Group 2 had the highest daily liveweight gain but because of a lower dressing percentage the corrected daily liveweight gain for these bulls was the lowest. These differences were not significant.

In Experiment III, no significant differences were observed in liveweight gain, carcass weight or dressing percentage between bulls fed silage of different maturity (Table 11). However, it was found that there was a tendency for bulls in group 2 to present the highest carcass weights and the highest daily gain.

In Experiment IV silage harvested one week after heading produced insignificantly lower carcass weights and daily weightgain than silage harvested at a later stage. Bulls on treatment B, given

Table 10. Mean initial and final liveweights, daily liveweight gain, carcass weight, dressing percentage and corrected daily gain for Experiments I and II

	Experiment I					Experiment II	
	Harvesting stage			Concentrate		Harvesting stage	
Groups	1	2	3	A	B	2	3
Initial liveweight, kg	387.0	391.2	390.3	389.3	389.6	352.1	352.1
Final liveweight, kg	477.9	469.0	473.5	462.6[a]	484.4[b]	433.2	428.7
Daily liveweight gain, g	1045	895	956	842[a]	1089[b]	1446	1366
Carcass weight, kg	238.5	231.7	237.2	226.4[a]	245.2[b]	212.2	216.5
Dressing percentage	49.9	49.2	50.1	48.8[a]	50.7[b]	49.0[a]	50.5[b]
Corrected daily gain, g [1)]	1035[b]	831[a]	966[b]	730[a]	1158[b]	1290	1442

[1)] Corrected to dressing percentage = 50

Table 11. Mean initial and final liveweights, daily liveweight gains, carcass weights, dressing percentage and corrected daily gain for Experiments III and IV

	Experiment III					Experiment IV				
	Harvesting stage			Concentrate		Harvesting stage			Concentrate	
	1	2	3	A	B	1	2	3	A	B
Initial liveweight, kg	315.2	315.3	315.6	316.0	314.7	346.0	344.0	348.3	345.6	346.5
Final liveweight, kg	424.1	433.8	427.4	417.0[a]	439.8[b]	467.0	469.5	478.0	462.4	480.6
Daily liveweight gain, g	1330	1445	1362	1232[a]	1526[b]	1120	1163	1201	1081[a]	1242[b]
Carcass weight, kg	205.1	207.8	202.2	197.0[a]	213.1[b]	225.0	228.3	231.2	218.8[a]	237.5[b]
Dressing percentage	48.2	47.9	47.4	47.2[a]	48.5[b]	48.1	48.7	48.4	47.3[a]	49.4[b]
Corrected daily gain, g[1)]	1157	1224	1086	950[a]	1361[b]	963	1043	1056	852[a]	1190[b]

[1)] Corrected to dressing percentage = 50

3.0 kg concentrate day^{-1}, had higher figures for liveweight gain, corrected liveweight gain, carcass weight and dressing percentage than bulls given 1.5 kg concentrate day^{-1} (treatment A).

F. Quality grades and carcass measurements

The results from the slaughter investigations are given in Tables 12 and 13. No substantial differences in quality grades between harvesting stages were shown, except in Experiment IV, where bulls in group 3 received the best grades. A trend was observed which indicated that bulls offered the higher level of concentrate had the best quality grades. Generally, the bulls were too lean to get the highest quality score (grade *).

In Experiment I there was a tendency for the weight of kidney fat to be reduced with later harvesting date, but

Table 12. Carcass characteristics, Experiments I and II

	Experiment I					Experiment II	
	Harvesting stage			Concentrate		Harvesting stage	
	1	2	3	A	B	2	3
No. of carcasses with							
Quality grade *	2	2	3	2	5	1	1
Quality grade I +	1	3	2	3	3	5	4
Quality grade I	2	1	1	3	1	0	1
Weight of liver, kg	5.5	5.0	5.2	4.9[a]	5.6[b]	5.5	5.7
Weight of kidney fat, kg	3.9	3.7	3.5	3.7	3.7	4.0[b]	2.9[a]
Conformation, points[1)]	12.1	11.8	12.3	11.4[a]	12.8[b]	12.2	11.7
Amount of fat, points[2)]	3.9[b]	2.5[a]	3.8[b]	2.6[a]	4.3[b]	4.5	3.8
Fat colour[3)]	2.2[a]	3.3[b]	3.0[b]	2.9	2.8	1.8	1.5

[1)] Scale 1 to 15 (15 best conformation)
[2)] Scale 1 to 10 (10 fattest)
[3)] Scale 1 to 10 (1 whitest)

Table 13. Carcass characteristics, Experiments III and IV

	Experiment III					Experiment IV				
	Harvesting stage			Concentrate		Harvesting stage			Concentrate	
	1	2	3	A	B	1	2	3	A	B
No of carcasses with										
Quality grade *	0	1	0	0	1	1	1	4	1	4
Quality grade I +	5	6	6	6	11	5	6	3	4	7
Quality grade I	3	1	2	6	0	2	0	1	2	1
Weight of liver, kg	5.4[b]	5.2[ab]	5.1[a]	4.8[a]	5.6[b]	5.6	5.5	6.0	5.4	6.0
Weight of kidney fat, kg	3.8[b]	3.1[a]	2.8[a]	3.2	3.3	4.8	3.6	4.3	4.2	4.3
Conformation, points[1)]	12.5	12.5	12.3	12.2	12.7	12.6	12.9	13.4	12.7	13.3
Amount of fat, points[2)]	2.5	2.0	2.3	2.2	2.3	2.8[a]	3.1[ab]	3.6[b]	3.1	3.2
Fat colour[3)]	2.0	1.8	2.1	1.8	2.2	2.5	1.9	1.9	2.2	1.9

[1)] Scale 1 to 15 (15 best conformation)
[2)] Scale 1 to 10 (10 fattest)
[3)] Scale 1 to 10 (1 whitest)

the estimated fat content was lowest in group 2. Bulls on 3.0 kg concentrate had significantly higher liver weight, a higher conformation score and a higher fat content, but not a higher weight of kidney fat than bulls fed 1.5 kg concentrate.

In Experiment II weight of kidney fat was significantly lower in group 3 than in group 2. Also, in Experiment III the weight of kidney fat showed a tendency to decrease with postponed harvesting stage, although there was no significant difference in fat content. Liver weight was reduced by delaying the harvesting stage. Again, the highest amount of concentrate gave a higher weight of liver, although no other parameter was influenced.

In Experiment IV, the lowest weight of kidney fat was found in group 2. However, the amount of fat tended to increase with postponed harvesting. Concentrate levels did not significantly alter any of the carcass characteristics.

G. Efficiency of feed conversion

In Tables 14 and 15 efficiency of feed conversion and net energy content calculated from the gain in the different groups are presented. When computing feed conversion, FU values calculated by value number 80 were used. The net energy content in the silage was calculated from the bulls requirements for liveweight gain and maintenance minus the net energy intake from the concentrate, as described by Saue et al. (1978).

In Experiment I the consumption of FU (kg corrected gain)$^{-1}$ for group 3 was lower than that for the other groups. The difference between groups 3 and 1, however, was not significant ($P = 0.24$). Energy content based on gain was increased by delayed harvesting stage. However, the difference observed between groups 1 and 3 was found to be not significant ($P = 0.13$).

In Experiment II, silage from the latest harvesting resulted in better feed conversion; the calculated energy content in the silage was higher, too. In Experiment III, bulls fed early harvested silage required a higher amount of FU in order to produce 1 kg corrected gain than bulls fed the later harvested silage (Table 15).

The FU value estimated by gain was highest for silage produced at the dough stage and lowest for silage from one week after heading. The difference was significant ($P = 0.03$). In Experiment IV no significant differences in feed efficiency or calculated FU value between harvesting stages were observed. In all experiments the highest amount of concentrate (3.0 kg) resulted in a more efficient conversion of FU to body weight gain than the lowest amount (1.5 kg).

H. Rumen studies

During Experiments II, III and IV rumen fluid samples were obtained using a stomach tube about three hours after the morning feeding. The average values of

Table 14. Efficiency of feed utilization and net energy value (FU) of the silage calculated from liveweight gain, Experiments I and II

	Experiment I					Experiment II	
	Harvesting stage			Concentrate		Harvesting stage	
	1	2	3	A	B	2	3
FU (kg gain)$^{-1}$	6.40	6.62	5.74	6.66^{b}	5.85^{a}	4.54	4.64
FU (kg corrected gain)$^{-1}$	6.48^{ab}	7.43^{b}	5.80^{a}	7.74^{b}	5.41^{a}	5.06^{b}	4.27^{a}
FU (kg DM)$^{-1}$	0.675	0.694	0.735	0.674	0.728	0.737^{a}	0.844^{b}

Table 15. Efficiency of feed utilization and net energy value (FU) of the silage calculated from liveweight gain, Experiments III and IV

	Experiment III					Experiment IV				
	Harvesting stage			Concentrate		Harvesting stage			Concentrate	
	1	2	3	A	B	1	2	3	A	B
FU (kg gain) [1]	4.95[b]	3.66[a]	3.60[a]	4.16	3.97	5.55	5.75	5.46	5.64	5.54
FU (kg corrected gain) [1]	5.93[b]	4.37[a]	4.54[a]	5.47[b]	4.43[a]	6.62	6.52	6.32	7.14[a]	5.83[b]
FU (kg DM) [1]	0.717[a]	0.824[b]	0.776[ab]	0.739	0.805	0.662	0.639	0.647	0.646	0.653

three different samples are given in Table 16.

In Experiment III there was a trend indicating an increasing proportion of acetic acid and a decreasing proportion of propionic acid in rumen fluid with postponement of silage harvesting stage; in Experiment IV, too, there was a tendency towards increased proportions of acetic acid. There was no significant difference in acid proportion between the concentrate levels. Ammonia concentration in rumen fluid generally showed a tendency to decrease with delayed harvesting stage, while higher concentrate feeding reduced the ammonia concentration.

DISCUSSION

A. Silage characteristics

The wide variation in rape content in the crop between harvesting stages and between experiments partly reflects the general problem of controlling the botanical composition of a mixed crop. Improvements in the cultivation technique have led to a more stable ratio of forage rape to barley in the mixture (Volden unpublished). The adverse weather conditions during the experimental years also contributed to the variable rape content. These factors influenced the comparison between the harvesting stages and made interpretation of the results difficult.

In agreement with the ensiling experiments (Nordang 1990a), the silages from all three harvesting stages were

Table 16. Molar proportion of volatile fatty acids, ammonia N and pH in rumen fluid

	Experiment II		Experiment III					Experiment IV				
	Harvesting stage		Harvesting stage			Concentrate		Harvesting stage			Concentrate	
	2	3	1	2	3	A	B	1	2	3	A	B
Molar percentage:												
Acetic acid	64.5	65.1	59.9[a]	63.5[b]	64.4[b]	62.3	62.9	65.2[a]	64.5[a]	67.1[b]	65.4	65.8
Propionic acid	18.5	17.9	21.6[b]	20.0[ab]	18.4[a]	20.3	19.7	18.9	19.6	18.7	19.4	18.8
Butyric acid	14.1	14.1	13.6[b]	11.7[a]	12.2[a]	12.4	12.6	11.4[b]	11.5[b]	10.0[a]	10.8	11.2
Isobutyric acid	0.70	0.72	1.28	1.33	1.25	1.26	1.31	1.11[b]	0.92[a]	0.93[a]	1.03	0.94
Valeric acid	1.26	1.20	1.86[b]	1.91[b]	1.80[a]	1.90	1.82	1.40[a]	1.52[b]	1.48[ab]	1.46	1.48
Isovaleric acid	0.94	0.99	1.73[a]	1.80[ab]	1.95[b]	1.82	1.83	1.89	1.94	1.82	1.94	1.82
Ammonia, mmol(L) [1]	15.4	12.5	9.41[c]	6.48[b]	5.09[a]	7.65[b]	6.33[a]	9.54[b]	7.32[a]	6.67[a]	8.67[b]	7.01[a]
pH	6.71	6.70	7.02	7.01	6.98	6.98	7.02	7.09[b]	6.97[a]	7.01[ab]	7.02	7.02
$(C_2 + C_4)/C_3$	4.32	4.49	3.48[a]	3.84[b]	4.24[c]	3.77	3.93	4.11	3.95	4.18	3.99	4.17

well conserved. However, the concentrations of acetic and lactic acid in the silage were higher in the present experiments. Butyric and propionic acid levels and the ammonia level were also elevated. These differences reflect the more ideal ensiling conditions found in the small-scale silos used in the ensiling experiments.

The low crude protein content of the silage may have been caused by low nitrogen application. In field experiments nitrogen rates up to 180 kg N ha^{-1} gave higher crude protein content in the crops without causing serious lodging problems (Volden unpublished).

In ensiling experiments with barley-fodder rape the change in digestibility and energy content by delayed harvesting date varied extensively from only a slight decrease to a substantial fall (Nordang 1990a). A similar variation was shown in these experiments. There seemed, however, to be no correlation with year. While there was no decrease in the energy content of the silage in Experiment IV, in the present series a noticeable decrease was found in the ensiling experiments at Vågønes Research Station in 1984 (Nordang 1990a).

B. Forage intake and growth rate

The voluntary intake of silage DM by ruminants is influenced by several factors, which include the OM digestibility, the DM content, the crude fibre content and the fermentation characteristics (Brenøe 1972, Hermansen 1980, Kristensen 1983). Furthermore, low content of crude protein in the ration may limit feed intake because of a low level of rumen degradable protein (Munksgaard et al. 1985).

In Experiment I the low DM intake in group 2 may possibly have been due to the fermentation characteristics of the silage, which had a higher content of butyric and propionic acids and ammonia than the other silages. In Experiment III the relative low intake in groups 2 and 3 may have been caused by the low digestibility of the silages. In Experiment IV, intake was lowest in group 1, which may be explained by a high content of crude fibre and a lower DM content in the silage.

Excluding Experiment II, the mean intakes of silage DM (100 kg liveweight) $^{-1}$ were 1.42, 1.37 and 1.36 kg for harvesting stages 1, 2 and 3, respectively. These figures were slightly lower than those found with grass silage (timothy) harvested at heading and two weeks later in similar experiments at the same farm (Bergheim 1979).

According to Norwegian recommendations (Homb 1981), the DCP requirement for growing bulls of between 12 and 18 months varies from 100 to 90 g FU^{-1}. In several cases the content of DCP in total rations was slightly below these recommendations. However, production experiments with fattening bulls have given adequate growth rates with lower DCP content in the ration (Ekern 1973).

In a review, Oldham & Smith (1982) concluded that with fibre-rich rations a total dietary crude protein content lower than 8.5% may reduce feed intake by growing cattle. In the present experiments, crude protein content was above this level in all groups.

Protein balance in the rumen (PBV) was calculated according to Madsen (1985); values from -31 to 4 g CP FU^{-1} were obtained. In experiments with growing bulls (Andersen et al. 1986a) and heifers (Andersen et al. 1986b), there were no reductions in feed intake, feed efficiency or weight gain, even at lower PBV values which makes it seem unlikely that the low protein content adversely influenced the feed intake or liveweight gain of the bulls.

Even though there was variation between experiments, the growth rate of the bulls was acceptable at all harvesting stages, and at least as high as that found by Bergheim (1979) on grass silage (first cut) with similar amounts of concentrate. In all experiments there was a good relationship between daily intake of silage

DM and corrected daily gain in the various groups.

However, the relation between daily intake of estimated net energy (FU) and corrected daily gain in the different groups was low. Generally, bulls fed low energy silage showed higher gains than expected from the intake of estimated net energy. This was most obvious in Experiment III, where the bulls in group 1 had a significantly higher net energy intake than the other two groups, but growth rate was at the same level. In Experiments I and II a similar tendency was observed, the bulls in group 3 having the lowest intake of FU, but corrected daily gain in this group was at the same level as the groups fed silage from earlier harvesting stages. In Experiment IV good correspondence between estimated net energy intake and growth rate was observed.

The data obtained at slaughter indicated that the composition of the carcasses differed among the groups. The weight of kidney fat decreased with delayed harvesting in Experiments I, II and III. The visual estimate of fat amount on the carcasses was not in agreement with the weight of kidney fat, but the latter was considered as the more reliable measurement for assessing carcass fat content. Consequently the bulls in group 3 would have required less energy (kg gain)$^{-1}$ towards slaughter than those in group 1. One possible explanation for the tendency toward leaner carcasses by postponed harvesting stage was the different energy supply in the groups, but such differences were not produced by increasing the level of concentrate from 1.5 to 3.0 kg.

The observed trend toward lower feed expenditure with delayed harvesting stage (Experiments I, II and III) may be explained by the composition of the carcasses. Lower fat content in the liveweight gain will reduce the requirement for growth and hence give a lower value for FU (kg corrected gain)$^{-1}$. The lower feed expenditure of bulls on 3.0 kg concentrate was in agreement with the higher daily liveweight gain, and consequently a smaller part of the total feed was required for maintenance than for the bulls fed 1.5 kg concentrate.

The net energy values calculated from the liveweight gain in Experiments I, II and III were not in correspondence with the energy values estimated from the digestibility trials, with the production experiments giving lower values at the H1 stage and higher values at the H3 stage. This could have been caused partly by the already discussed differences in carcass composition. Because the requirement for growth was considered equal in all groups, 2.5 FU (kg corrected liveweight gain)$^{-1}$, an underestimation of the energy value of the silage in group 1 would be expected. However, the observed differences in fat content in the carcasses were not large, and the discrepancy between the net energy intake and the gain of the bulls may also have been due to other reasons. It must be recalled that the estimated FU values were based on digestion trials with sheep at maintenance level, and both feeding level and concentrate supplements may alter digestibility of the ration. It is also possible that the quality of the silage sampled for digestibility trials differed from that used throughout the experiments. However, no such differences were registered by the chemical analysis. On the other hand, the utilization of digestible energy might have been different between the groups.

Moe & Tyrrell (1980) found a major difference in the amount of methane produced during the digestion of various carbohydrate fractions. The production of methane per gram of cellulose was five times that of gram digested soluble carbohydrates, primarily starch. In the present experiments the amount of digestible crude fibre declined rapidly the more the harvesting stage was delayed, and possibly gave less energy loss in methane. That being the case, then the FU system would have given too high an

estimate of the net energy value of early harvested barley-rape silage related to the late harvested silage.

In spite of the variation observed, it can be concluded from the bull feeding experiments that the decrease in feeding value with delayed harvesting stage may be moderate, and that barley-fodder rape silage, regardless of ripeness stage, may serve as the sole forage component in rations for fattening bulls. To adjust liveweight gain and carcass quality, it may be necessary to have a relatively high level of concentrate in the ration. In addition, the protein content in the concentrate would have to be high enough to satisfy the bulls' requirements.

When comparing the different harvesting stages, certain other factors should also be considered: crop yield, effluent losses and crop rotation.

The yield of FU ha^{-1} was calculated from DM yield and FU values estimated from digestibility trials (D) and from the production experiments (P). The following values were obtained:

	Experiment II		Experiment III			Experiment IV		
	2	3	1	2	3	1	2	3
D	5500	5100	3300	3400	3600	3200	6200	6600
P	5700	5900	3000	4500	5000	2900	5400	6100

From these gross yield figures ensiling losses should be subtracted. In ensiling experiments effluent DM losses decreased significantly as maturity stage was postponed. The net energy yield increased substantially until dough ripening of barley, but after that the increase was low.

Compared to the average yield of one- to four- year-old grassland fields in a two-cut system at Vågønes, 5000 to 5500 FU ha^{-1} (Larsen unpublished), the yield of barley-fodder rape is quite high. On farms with a serious lack of forage following winter-damaged grassland and also on farms with a more normal supply of forage, barley-fodder rape mixtures seem to produce a valuable crop.

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