Norwegian Journal of Agricultural Sciences

Vol. 5 1991 No.3

Norwegian Agricultural Advisory Centre, Ås, Norway

NORWEGIAN JOURNAL OF AGRICULTURAL SCIENCES

Norwegian Journal of Agricultural Sciences fills a need created by the folding of Scientific Reports of the Agricultural University of Norway and Research in Norwegian Agriculture for a forum for publishing Norwegian research with international interest within the following areas: Aquaculture, Animal Science, Soil Science, Agricultural Engineering and Technology, Natural Resources and Environment, Food Technology, Crop Science, Forestry, Economics and Society Planning.

PUBLISHER

The journal is published by Norwegian Agricultural Advisory Service, Moerveien 12, N-1432 Ås, Norway. Norwegian Journal of Agricultural Sciences (ISSN 0801-5341) is published four times a year, each issue containing approximaterly 100 pages. Four issues comprise one volume. Annual subscription NOK 400,–. Subscribers receive supplement issues free of charge, but these can also be ordered separately through the publisher.

CORRESPONDENCE

All Correspondence, editorial or otherwise, should be adressed to Norwegian Agricultural Advisory Service.

The drawing on the cover is from Kjell Aukrust's *«Guttene på broen»*.

ISSN 0801-5341

Substitution of dip-treated straw for grass silage in dairy cows

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Xu, S., Å.T Randby & F. Sundstøl, 1991. Substitution of dip-treated straw for grass silage in dairy cows. Norwegian Journal of Agricultural Sciences 5: 209-219. ISSN 0801-5341

In 1987 and 1988 twenty-four Norwegian milking cows were used in a study of the influence on milk production when the animals were fed grass silage and dip-treated straw supplemented with urea or with soybean meal. In 1987 the percentage of fat corrected milk (4%) was higher for the cows fed treated straw than it was for the cows fed grass silage. In 1988 there was no significant difference between the groups. The ruminal pH was higher when the animals were fed dip-treated straw in both years. The magnesium content in blood plasma was lower for cows fed treated straw than for those fed grass silage. There were no clinical problems among the animals connected with the experimental feeds in either year.

Key words: Dairy cows, dip-treated straw, grass silage, milk yield, urea.

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The upgrading of roughages, e.g. straw, by chemical agents has been studied extensively in the last few decades. A historical review of the studies is given by Sundstøl (1988).

Treatment of straw with NaOH solution reduces the proportion of cell walls in straw (Fahmy & Sundstøl 1985). The digestibility of straw can be increased by 15-20 percentage units, sometimes even more, by treatment with NaOH (Wanapat et al. 1985).

Straw per se is very low in crude protein (CP) (N*6.25), i.e. 2-4%. However, NaOH-treated straw supplemented with urea or intact protein as a N source for microbial protein synthesis in the rumen is a promising and attractive roughage (Sundstøl & Randby 1988).

Studies on milk production responses of dairy cows fed on NaOH-treated straw have been reported (Kristensen et al. 1977, Randby 1984, Roberts 1988). The conclusion is that satisfactory results can be achieved when ruminants are fed NaOH-treated straw along with CP or non protein nitrogen (NPN) supplementation, even when treated straw constitutes the main part of the ration.

The objective of the present experiments was to study the influence on milk production of feeding mid-lactation cows

dip-treated straw as the main part of the diet as compared with feeding cows grass silage.

MATERIALS AND METHODS

In 1987 and 1988 two experiments were carried out at Hellerud Experimental Station in which a comparison was made between dip-treated straw with or without urea and grass silage as feed for milking cows.

The two experiments followed the same plan, twenty-four Norwegian Red Cows in mid-lactation being employed in each. The cows were divided into three groups on the basis of milk yield, fat percentage, calving date and parturition number. The experiments comprised a preliminary period of four weeks, an experimental period of nine weeks (eight weeks in 1988) and a post-experimental period of four weeks. The same diets were given to the three groups in the preliminary and post-experimental periods except that a lower level of concentrate was given in the latter period. All cows were given 100 g Mg-enriched mineral mixture (Norsk Mineralnæing) daily during the experimental period. The treatments in the experimental periods are given in Table 1.

Both concentrates and roughages were fed in restricted amounts in the two experiments. Concentrates were given according to the milk yield of each cow (Breirem 1984). The diets (Table 1) were formulated so as to be nearly isonitrogenous for the three groups.

Dip treatment

The method for NaOH treatment of barley straw used in these experiments was the dip treatment method described by Sundstøl (1981).

At the experimental farm the treatment was carried out using four steel vessels 6.5m^3 (2.75 m * 1.40 m * 1.65 m) with a capacity of about 500 kg straw. Two vessels were used for dip treatment of straw with urea (A) and the other two for dip treatment of straw without urea (B). The straw was soaked in a solution of NaOH (15 g/l) for 45 min and then stored for three to five days before being used for

Table 1. The daily rations planned for the 1987 and 1988 experimental periods

	kg DM	Fattening feed units (FFU)
Group 1		
Grass silage	8.4	6.0
Barley meal	1.3	1.5
Concentrate mixture	(according to milk yield)	
Group 2		
Grass silage	2.8	2.0
Dip-treated straw	6.2	4.0
Urea , g	260 (192)[1)]	
Barley meal	1.3	1.5
Concentrate mixture	(according to milk yield)	
Group 3		
Grass silage	2.8	2.0
Dip-treated straw	6.2	4.0
Soybean meal	1.4	1.5
Concentrate mixture	(according to milk yield)	

[1)] 192 g urea was used in the 1988 experiment

feeding. The NaOH solution was replenished by adding 6-6.5 kg NaOH per 100 kg straw. In vessel A urea was added to a concentration of 12 g/l and Na_2SO_4 to reach 2 g/l of the NaOH solution. An N:S ratio of 10:1 was attempted (Silva & Ørskov 1988).

The mean concentrations of the NaOH solutions in the experiments in 1987 and 1988 are given in Table 2.

Table 2. The mean concentrations of the NaOH solutions for treatment of barley straw in the 1987 and 1988 experiments (g/l)

	Experimental year 1987	1988
Strength of NaOH solution without urea	14.9	14.3
Strength of NaOH solution with urea	14.8	14.4
Urea in the solution	12.5	12.2
Na_2SO_4 in the solution	2.1	*

* 33 g Na_2SO_4 per day was sprayed on the feed for each cow fed dip-treated straw with urea instead of mixing it with the NaOH solution

Grass silage-making

The grass silage for the experiments was prepared from the first and second cuts of grass mixtures of timothy, meadow fescue and red clover at Hellerud Experimental Station.

Digestibility experiments

A representative amount of dip-treated straw with or without urea and silage was taken every week in the experimental period of the feeding trials for digestibility determination. Two mature wethers were used per treatment in the digestion trials, which comprised an 11-day adaption period followed by a 10-day total collection period. The animals received 800 g DM of grass silage, dip-treated straw with urea or dip-treated straw without urea, respectively. The animals fed treated straw were supplemented with 75 g herring meal daily. All the sheep were given 10 g salt and 10 g mineral mixture daily. Water was available throughout. Feeds were given at 07.30 and 15.30 h in two equal portions. Faeces were quantitatively collected daily from each sheep in the collection period. Samples of feeds and faeces were analysed for chemical composition following the standard procedure.

Chemical analysis

The dry matter (DM) of silage and dip-treated straw with or without urea was determined every week in order to adjust the daily amounts of feed according to the plan (Table 1). The rest of the samples were frozen and reserved for chemical analysis of DM, ash, crude fibre (CF), ether extract (EE), nitrogen (N) (AOAC 1980) and nitrogen free extracts (NFE) were calculated by difference. The individual milk yield of the cows was recorded twice daily (morning and evening), four days a week. Samples were taken for determination of fat, protein and lactose in milk (Fellesmeieriet, Oslo). The content of DM, ash, energy, urea and minerals (Na ,K , Ca, Mg) in the milk was also analysed (AOAC 1980).

Blood samples were taken through the jugular vein in the preliminary, experimental and post-experimental periods. The samples were centrifuged at 3000 rpm for 15 min and the plasma was taken for analysis of mineral concentration (AOAC 1980), and urea concentration (Kapalan 1987).

The rumen liquor of the cows was collected each period by vacuum through a stomach tube. The first part of the sample was discarded. pH was measured using a pH meter immediately after sampling. Ammonia-N was determined by means of an automated colorimetric method (Logsdon 1960) and volatile fatty acids (VFA) by gas chromatography (PYE-Unicam GCD), using a glass column packed with Chromosorb 101, 60-80 mesh (Johns-Manville). The column temperature was 175°C and the carrier gas (N_2) flow rate was 75 ml/min. Detection was by hydrogen flame ionization

Table 3. The chemical composition of the feeds

	Grass silage	Dip-treated straw with urea	Dip-treated straw without urea	Barley meal	Soybean meal	Concentrate mixture[1)]
1987 expt.						
Dry matter, %	23.9	26.7	26.1	87.2	89.7	89.2
In DM g/kg:						
Ash	59	154	152	24	62	66
N * 6.25	183	155	60	130	501	190
Ether extract	61	15	14	20	16	59
Crude fibre	291	342	361	54	64	74
NFE	406	413[2)]	413	772	357	611
1988 expt.						
Dry matter, %	23.0	24.8	24.8	86.7	88.4	88.8
In DM g/kg:						
Ash	60	129	135	23	69	62
N * 6.25	173	134	35	113	484	161
Ether extract	61	28	29	24	15	65
Crude fibre	327	441	442	51	79	64
NFE	380	367[2)]	359	789	353	648

[1)] Ingredients: fish meal 10%; oats 45%; barley meal 37.5%; molasses 4.2%; rendered fat 0.5%; minerals and vitamins 2.8%

[2)] NFE = Nitrogen free extracts after correction of protein (N*6.25) for urea-N

and quantities were expressed at an integrator (HP3380A).

Statistical treatment of data of blood samples, rumen liquor and milk yield followed the method for analysis of covariance (SAS 1986), using data for the preliminary period and post-experimental periods as covariates.

RESULTS

The values for chemical composition of the feeds used in the experiments are given in Table 3.

Table 4 gives the pH, NH_3-N and organic acid content in the grass silage used in the two experiments.

The DM content of the silage was nearly the same in the two experiments. The CP (N*6.25) content of silage was slightly lower in 1988 and CF somewhat higher than in 1987. The average pH of grass silage in 1987 was slightly lower compared with that in 1988. The content of NH_3-N in total N of grass silage was 37% less in 1987 than in 1988. The organic acids in grass silage did not vary much between the two years and were within the normal range (Breirem & Homb 1970). The DM content of dip-treated straw with and without urea was higher in 1987 than in 1988 as was the ash and CP content as indicated in Table 3. Barley meal, soybean meal and especially the concentrate mixture displayed

Table 4. The pH, NH_3-N and organic acid concentrations in grass silage in 1987 and 1988

	1987	1988
pH	3.89	4.10
NH_3-N in % of total N	3.86	6.14
Formic acid, %	0.22	0.36
Propionic acid, %	0.02	0.01
Lactic acid, %	1.40	0.82
Acetic acid, %	0.36	0.56
Butyric acid, %	0.00	0.00

Table 5. Apparent digestibility and estimated metabolizable energy content of grass silage (Group 1), dip-treated straw with urea (Group 2) and without urea (Group 3) by sheep (%)

	1987			1988		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Dry matter	68.8[b]	69.8[b]	72.3[a]	73.4[a]	54.3[b]	52.5[c]
Organic matter	71.9	73.7	74.3	75.7[a]	55.7[b]	54.4[b]
N * 6.25	75.1[a]	71.0[a]	37.1[b]	73.5[a]	70.0[a]	-9.6[b]
Ether extract	74.4[a]	42.9[b]	47.5[b]	75.5[a]	22.8[b]	20.9[b]
NFE	68.8	64.3	69.9	69.8[a]	14.7[c]	31.8[b]
Crude fibre	74.1[b]	87.2[a]	87.3[a]	84.2[a]	82.4[ab]	79.4[b]
MJ ME/kg DM	10.9	10.6	10.6	11.6a	7.4[b]	6.9[c]

Two sheep were used on each diet.
Differences between means with the same superscripts within the experiment (a,b, or none) are not significantly different ($p < 0.05$)

the same tendency in that both DM and CP were higher in the 1987 trial than in the 1988 trial.

The digestibilities of grass silage, dip-treated straw with urea and dip-treated straw without urea determined in sheep (along with feeding trials) are given in Table 5. The digestibilities of dip-treated straw with or without urea presented in Table 5 were calculated by difference correcting for the digestibility of the herring meal. The digestibilities of DM and organic matter (OM) of dip-treated straw with or without urea in 1988 were considerably lower than in 1987. CP (N*6.25) digestion was improved by adding urea to NaOH solution in both experiments. The digestibility of CF in dip-treated straw was very high, especially in 1987.

The difference in energy value between silage and dip-treated straw was small in 1987 but much lower values for dip-treated straw were found in 1988.

The amounts of feed consumed by the cows in the two feeding experiments are given in Table 6.

Because of their slightly higher milk yield the cows fed dip-treated straw in 1987 were given more concentrate mixture than the silage fed cows. In 1988 the difference was rather small. The milk yield, milk composition and energy content of milk are given in Table 7.

It should be noted here that the values presented in Table 7 and following tables were analysed by covariance among the three groups within the experiment.

In 1987, milk yield (kg), 4% fat-cor-

Table 6. Feed consumption in cows fed different diets (kg DM/day)

	1987			1988		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Grass silage	7.8	2.9	2.9	7.8	2.9	2.9
Dip-treated straw with urea		6.3			5.7	
Dip-treated straw without urea			6.4			5.8
Barley meal	1.7	1.7		1.3	1.4	
Soybean meal			1.7			1.4
Concentrate mixture	4.8	5.7	6.4	6.3	5.7	6.2
Total DM intake	14.3	16.6	17.5	15.4	15.7	16.3

Table 7. Performance of the cows and milk content

	1987			1988		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Milk yield	26.1[b]	27.1[ab]	28.3[a]	25.1	24.2	24.8
Fat-corrected milk	23.1[c]	24.7[b]	26.4[a]	24.7	23.8	24.0
Content of milk:						
Fat %	3.39	3.43	3.45	3.91	3.89	3.82
Protein %	3.15	3.15	3.14	3.16[a]	3.08[b]	3.16[a]
Lactose %	4.92[b]	5.05[ab]	5.07[a]	5.13[b]	5.23[a]	5.24[a]
Ash %	0.69[a]	0.66[b]	0.68[ab]	0.72[a]	0.67[c]	0.70[b]
Energy, kJ/g	2.7	2.8	2.8	2.9	2.8	2.9
Live weight change, g/d	310	230	310	193	-214	24

Superscripts see Table 5

rected milk (FCM) and fat content were significantly lower for the silage fed cows than for those fed dip-treated straw. In 1988 no such differences were found.

The protein content of the milk from cows fed dip-treated straw with urea in 1988 was lower ($p < 0.05$) than that from cows fed silage or dip-treated straw supplemented with soybean meal. The lactose content of the milk from animals fed silage was lower than that from animals fed dip-treated straw in both years. The ash content of the milk was significantly higher for the silage fed animals than for the straw fed animals. There were no significant differences between treatments with regard to DM and energy content, but both tended to be higher in milk from 1988 than in milk from 1987.

The live weight gains of cows during the experimental period were much lower in 1988 than in 1987. Cows fed dip-treated straw with urea lost body weight in 1988.

The pH levels and concentrations of ammonia-N and VFA in the rumen liquor from cows fed the different diets are given in Table 8.

Table 8. The pH values and concentrations of ammonia-N and VFA in the rumen liquor of cows fed silage (Group 1), dip-treated straw with urea (Group 2) or dip-treated straw supplemented with soybean meal (Group 3)

	1987			1988		
	Group	Group	Group	Group	Group	Group
	1	2	3	1	2	3
pH	6.6[b]	6.9[a]	6.8[a]	6.8[b]	7.1[a]	7.0[a]
Ammonia-N mmol/l	12.2[ab]	15.1[a]	9.6[b]	12.9[a]	12.4[a]	4.8[b]
Total VFA mmol/l	94.4[c]	99.6[b]	103.9[a]	88.8	86.8	85.5
Individual VFA, Mol%:						
Acetic acid	63.8[b]	66.4[a]	66.7[a]	63.1[b]	68.3[a]	65.6[ab]
Propionic acid	19.4[a]	19.1[ab]	17.9[b]	19.2	19.6	19.8
Isobutyric acid	0.9[a]	0.7[b]	0.8[ab]	1.5[a]	0.7[b]	1.0[a]
Butyric acid	12.5[a]	11.4[b]	12.0[ab]	12.4[a]	10.3[c]	11.9[ab]
Isovaleric acid	2.0[a]	1.3[b]	1.4[b]	2.1[a]	0.5[c]	0.9[b]
Valeric acid	1.6[a]	1.0[b]	1.0[b]	1.7[a]	0.6[b]	0.8[b]

Superscripts see Table 5

The pH in the rumen liquor was higher when the animals were fed dip-treated straw compared with that when they were fed silage ($P < 0.05$).

The ammonia-N concentration in the rumen liquor was higher for cows fed silage or dip-treated straw with urea compared with cows fed dip-treated straw supplemented with soybean meal. The lowest ammonia-N concentration (4.8 mmol/l) was measured in cows fed dip-treated straw supplemented with soybean meal in 1988.

The total VFA (mmol/l) was generally higher in 1987 than that in 1988 and in 1987 the VFA production tended to be higher for the straw fed animals than in animals fed grass silage. Higher concentrations of isobutyric, isovaleric and valeric acids were observed in silage fed groups compared with dip-treated straw fed groups in the two experiments.

The concentrations of urea and certain minerals such as Mg, Na, K and Ca in the blood plasma of cows fed different diets are given in Table 9.

Table 9. The concentrations (mmol/l) of urea and certain minerals in blood plasma when cows were fed silage (Group 1), dip-treated straw with urea (Group 2) or with soybean meal (Group 3)

	1987			1988		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Urea	7.43[a]	5.81[b]	6.96[a]	7.34[a]	6.06[b]	3.26[c]
Magnesium	1.02[a]	0.88[b]	0.93[a]	1.01	0.93	0.88
Sodium	143.8	146.1	147.7	142.5	142.8	143.6
Potassium	4.04[ab]	3.96[b]	4.29[a]	4.18	4.02	4.17
Calcium	2.62	2.59	2.59	2.15[ab]	2.05[b]	2.16[a]

Superscripts see Table 5.

The urea concentration in blood plasma from both experiments was higher for silage fed groups than for those fed dip-treated straw. The content of magnesium in the blood was slightly lower in cows fed dip-treated straw compared with that of cows fed silage. The sodium concentration did not rise when NaOH-treated straw was fed. The calcium content in the blood was lower in 1988 than in 1987. Compared with the normal physiological range, the calcium concentrations in 1988 and the potassium concentrations of Group 1, Group 2 in 1987 and Group 2 in 1988 were relatively low.

In the 1988 experiment four cows in each group were given 50 g extra MgO daily besides the normal mineral mixture. The mineral concentrations in the blood for the two sub-groups of each treatment are given in Table 10.

The results indicated that extra Mg

Table 10. The comparison of blood plasma mineral concentrations in cows given high (50 g MgO extra per day) and normal Mg supplementation (mmol/l)

	Grass silage		Dip-treated straw with urea		Dip-treated straw with soybean meal	
	High	Normal	High	Normal	High	Normal
Calcium	2.28	2.18	2.19	2.16	2.24	2.21
Magnesium	1.06	0.99	0.98	0.86	0.93	0.82
Potassium	3.99	4.06	3.93	3.61	3.83	3.69
Sodium	140.37	142.37	142.37	144.00	142.25	142.50

Table 11. The content of urea and minerals in milk (mmol/l)

	1987			1988		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Urea	5.78[a]	4.61[c]	5.20[b]	5.31[a]	4.56[b]	4.48[b]
Magnesium	4.96	4.81	4.79	4.61	4.55	4.54
Sodium	25.42	26.41	26.91	21.23[a]	17.49[b]	18.51[ab]
Potassium	42.06[a]	40.73[b]	40.36[c]	44.75	44.06	44.41
Calcium	39.97	41.35	39.90	15.55	14.43	14.36

Superscripts see Table 5

supplementation elevated the content in the blood although no significant differences were observed. Also, blood calcium tended to be slightly higher when extra Mg was given.

The content of urea and certain minerals in the milk in the experiments is given in Table 11.

The urea concentration in milk from cows fed treated straw was significantly lower in both experiments compared with that of cows fed grass silage. The differences in magnesium content were generally small. The sodium concentrations in milk from cows fed NaOH-treated straw seemed to be high in 1987, but the findings were the opposite in 1988. The concentrations of calcium in the milk were obviously low and it was suspected that this was due to technical error during the analysis.

DISCUSSION

No health problems occurred in any of the treatment groups during the 16 weeks of each of the two experiments. Barley straw soaked in NaOH solution consequently increased the ash content in the straw. This is in accordance with the observations by Sundstøl (1981). The nitrogen content of the treated straw is enhanced by mixing urea into the NaOH solution as shown also by Xu (1986).

The apparent digestibility of OM in dip-treated straw is normally about 66-70% (Sundstøl 1981). In the present experiments even higher values were obtained in 1987. Lower digestion coefficients and estimated metabolizable energy were found in 1988. The quality of original straw played an important role in this case. When comparing the barley straw used over two years, the straw in the first experiment was harvested and baled under favourable weather conditions and then barn dried. In the second experiment the straw was prepared during wet weather with a precipitation of 101 mm, about four times that of the first year. The straw had a high moisture content and some of the bales became mouldy during the storage in an old shed. The results observed in this study were not in agreement with the findings by Kjos et al. (1987) which showed that dip treatment can even-out the difference between "good-quality straw" and "weather-damaged straw". However, in the present experiment (1988) the straw was quite heavily moulded, in contrast to the experiment of Kjos et al. (1987) in which the straw was only slightly attacked by mould. The weather-damage of straw in their experiment refers mainly to leaching of cell content in the rainly weather.

Production experiments with NaOH-treated straw (dry treatment) fed to dairy cows in comparison with untreated straw and grass silage were conducted by Kristensen et al. (1977). The general conclusion was that there was a tendency toward a higher milk yield for cows fed

NaOH-treated straw than for cows in the other two groups. In earlier experiments at Hellerud when grass silage was replaced by dip-treated straw to dairy cows on an energy basis (NOFO 1989) the milk yields in the treatment groups were almost similar. In the present study the performance of cows fed dip-treated straw with urea or supplemented with soybean meal in 1987 was superior to that of animals fed grass silage. A slightly higher concentrate mixture intake for groups fed treated straw (Table 6) may, to some extent have contributed to a higher milk yield. In 1988, however, the production of the cows fed treated straw was similar to that of cows fed grass silage. The live weight changes indicated that the dip-treated straw, which was affected by the wet weather during harvest, had a lower nutritive value than the grass silage. This was also in accordance with the lower digestibility and estimated metabolizable energy for dip-treated straw as indicated in Table 5. Kristensen et al. (1977) found that neutralization of NaOH-treated straw with HCl gave a constant ruminal pH value from 6.8 to 7.0 when cows were offered such a feed. Similar pH (6.8-7.1) values were obtained in the present study, supporting earlier observations which show that the excess NaOH in dip-treated straw is neutralized by the straw itself during the time of ripening (3-4 days) (Sundstøl & Randby 1988).

Since urea from dip-treated straw and amides from grass silage are rapidly dissolved in the rumen, the ammonia-N concentration was higher for these groups than for the group of animals fed dip-treated straw supplemented with soybean meal which is degraded slowly and to a lesser extent. Borhami & Johnsen (1981) found that a peak in ruminal NH_3-N concentration occurred at 6 h after feeding when the sheep were given NaOH-treated straw supplemented with soybean meal.

The utilization of ammonia-N by microbes in the rumen depends very much on the degradability of carbohydrates in the rumen. To what extent dip-treated straw can provide a carbon skeleton for microbial protein synthesis is still not quite clear. Xu & Sundstøl (1991) conducted an in sacco experiment with dairy cows to study the rumen degradation of dip-treated barley straw. The results showed that the degradability of dip- treated straw was 71%, compared with 42% for untreated straw at 48 h. The potential for microbial protein synthesis on dip-treated straw is also demonstrated by Fahmy & Sundstøl (1984).

Compared with cows fed dip-treated straw the animals fed grass silage produced more branched chain VFA in the rumen (Table 8). These acids are recognized as important precursors for synthesis of bacterial protein (Saxena et al. 1971). Both branched chain fatty acids and straight chain acids (C-5 to C-8) are required for the growth of *Bacteroides succinogenes*, a cellulolytic bacteria present in the rumen (Bryant & Doetsch 1955).

The sodium concentration in blood plasma of cows fed dip-treated straw was not affected by the dietary excess of Na as a result of the NaOH added at treatment. This is in agreement with O'Connor et al. (1988), but the plasma K concentration was not increased by a high level of Na in the diet used in the present study. The plasma Mg concentration was clearly lower when cows were given dip-treated straw as compared with silage. This is in accordance with other studies (Moseley & Jones 1974, Arndt et al. 1980). When 50 g MgO was administered to cows orally the plasma Mg concentration was elevated, confirming the observations of Jesse et al. (1981), Thomas et al. (1984) and Teh et al. (1985).

SUMMARY

Grass silage as feed for dairy cows was compared with dip-treated barley straw (NaOH) supplemented with either urea

or soybean meal. Twenty-four cows in mid-lactation were used each year. The apparent digestibility and estimated metabolizable energy of the feeds were determined in sheep at maintenance.

The values for digestibility of OM of grass silage, dip-treated straw with urea and dip-treated straw without urea were 71.9, 73.7 and 74.3% respectively in 1987, while in 1988 the values for digestibility of OM for dip-treated straw with or without urea were rather low compared with those for grass silage (75.7 vs. 55.7, 54.4, $p < 0.05$). The estimated metabolizable energy content of the treated straw was identical to that of grass silage in 1987, but much lower than that in 1988.

The milk production (4% fat-corrected milk) in 1987 was highest for the cows fed treated straw supplemented with soybean meal (26.4 kg), followed by the cows fed treated straw with urea (24.7 kg) and then silage fed cows (23.1 kg). In 1988 there was no significant difference between the groups.

The live weight gain of the cows fed treated straw was lower in 1988 than in 1987, confirming the lower energy values found in the digestibility experiments.
The ruminal pH was higher for cows fed treated straw with urea or soybean meal than that for cows fed grass silage in the two experiments ($p<0.05$).

The ammonia-N concentration (mmol/l) in the rumen liquor was lower for the cows fed treated straw supplemented with soybean meal than that for the cows fed either silage or treated straw with urea. The proportion of branched chain VFA (mol%) was higher for silage fed cows than for cows fed treated straw.

In both experiments higher urea concentrations (mmol/l) in blood plasma were found for silage fed cows than for cows fed treated straw. The magnesium concentration in the plasma was lower for the cows fed treated straw compared with those fed silage. The differences reached the significance level in 1987 ($p<0.05$).

No health problems occurred among the cows in these experiments which lasted for 16 weeks each.

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Digestion and duodenal flow in cows fed dip-treated barley straw and concentrates supplemented with urea or fish meal

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The aim of this study was to assess the digestibility of dip-treated straw and the microbial nitrogen production in the rumen of cows fed dip-treated straw/concentrates supplemented with either urea or fish meal. The cows used were surgically equipped with a permanent rumen fistula and a duodenal cannula. The organic matter digestibility of dip-treated straw/concentrates supplemented with either urea or fish meal was similar in the two experiments. The excretion of N in the urine tended to be higher when the cows were fed the diet with urea. Supplementation of fish meal as compared with urea had no significant effect on bacterial protein synthesis in the rumen in this study.

Key words: Digestibility, dip-treated straw, fish meal, fistulated cow, markers, microbial protein synthesis, urea.

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The limitations in the nutritive value of roughages can be overcome by chemical treatment. In recent decades alkali agents such as NaOH or ammonia have been studied extensively for this purpose.(Kristensen et al. 1977, Sundstøl et al. 1978, 1979, Sundstøl 1984).

The content of cell wall components of barley straw, of which approximately 38-42% is cellulose and 25-30% is hemicellulose (Silva & Ørskov 1988), is reduced by NaOH treatment (Kristensen et al. 1977). The digestibility of organic matter (OM) can be elevated from 45-50% to 75% (Wanapat et al. 1985). Supplementing NaOH-treated straw with urea as an N source for dairy cows gave similar milk production as supplementation with soybean meal (Randby & Xu 1988). The digestion of cell walls of roughages by the rumen microbes has been reviewed by Demeyer (1981).

The objectives of the present experiments were to study the digestibility of NaOH-treated barley straw supplemented with either urea or fish meal and to measure the microbial protein synthesis in the rumen by analysis of diaminopimelic acid (DAPA) as a microbial marker in the duodenal flow.

Table 1. Diets used in Expts 1 and 2

Feeds	Diet A, treated straw with urea			Diet B, treated straw with fish meal		
	DM kg/d	Feed units	Dcp g	DM kg/d	Feed units	Dcp g
Dip-treated straw with urea	6.2	4.0	575	-	-	-
Dip-treated straw without urea	-	-	-	6.2	4.0	-
Fish meal	-	-	-	0.757	0.97	575
Barley meal	3.0	3.5	284	3.0	3.5	284
Oat meal	3.1	4.0	280	3.1	4.0	280
Molasses	0.239	0.2	5.5	0.239	0.2	5.5

Dcp = Digestible crude protein.

MATERIALS AND METHODS

Animals and diets

Two cows were used in the first experiment (Expt 1) in the spring of 1989 and three cows in the second experiment (Expt 2) in the autumn of 1989. All the animals employed in this study were at the late stage of lactation. Each cow was surgically equipped with a permanent rumen fistula, inner diameter 10 cm, and a T-shaped duodenal cannula, inner diameter 2.5 cm. Shortly after the first experimental period of Expt 2 one of the cows in the experiment contracted mastitis and was replaced by another cow (reserve). The two diets compared in the experiments were formulated so as to be isonitrogenous. The ingredients are given in Table 1.

Barley straw was treated with a NaOH solution (1.5% w/v) according to the dip treatment method (Sundstøl 1981). Dip-treated straw with urea was obtained by mixing urea into a NaOH solution (11 g/l). The fish meal used in the two experiments originated from the same batch and had a high degradability (70%). The two diets (Table 1) were planned to cover the maintenance and production requirements of the animals.

In Expt 1 each cow received the two diets in two consecutive periods (changeover, 2*2), whereas in Expt 2 the two diets were compared with three cows in three periods (double reversal), rendering five observations for diet A and four observations for diet B. Each period of the experiments lasted for 23 days, during which digestibility and duodenal digesta flow were measured.

Digestibility experiments

There was an 18-day preliminary period and a 5-day total collection period. The daily ration was divided into four equal parts and fed at 08.00 and 14.00 h by hand, and 20.00 and 02.00 h by automatic feeder. The cows were given a 100 g magnesium-rich mineral mixture per day and had free access to water throughout. Faeces and urine were quantitatively recorded and 10% of each was collected daily and stored deep frozen during the collection period. Samples of feeds and excreta were prepared at the end of each period for chemical analysis and energy determination (bomb calorimetry).

Study of duodenal digesta flow

The flow of digesta to the duodenum was estimated by means of inert markers. The following markers were used in the study: A: Ytterbium acetate (Yb-Ac): a particulate marker, prepared as described by Siddons et al.(1985). Yb-Ac was continuously infused into the rumen through the rumen fistula. B: Chromic oxide (Cr_2O_3): a capsule containing 8 g each, made by Pharmacaps Ltd., Bucks,

England. One capsule of Cr_2O_3 was given through the rumen fistula at 08.00 h and one at 14.00 h.

Sampling and analysis

The samples of dip-treated straw with and without urea were freeze-dried. The feeds, faeces and urine were analysed for dry matter (DM), ash, crude fibre (CF), crude protein (CP = N * 6.25) and nitrogen free extract (NFE) by difference according to the standard procedure(AOAC 1980). True protein was analysed as described in a mimeographed paper (Rasjonaliseringsutvalget for Statens landbrukskjemiske kontrollstajoner av 1960 (1964) with later modifications). Hemicellulose, cellulose and lignin were assessed by the Goering & van Soest (1970) method.

In each experimental period, blood samples were taken from the jugular vein in heparinized tubes at 08.00 h in Expt 1 and at 0.800, 10.00, 12.00 and 14.00 h in Expt 2. The samples were centrifuged at 3000 rpm for 15 min and plasma was taken for analysis of certain minerals (AOAC 1980) and urea concentration (Kapalan 1987).

The rumen liquor was taken at 08.00, 10.00, 12.00, 15.00, 17.00 and 19.00 h on three consecutive days in each period using a tube sucked through the rumen fistula. The pooled values represent the period. The pH was measured immediately using a pH meter. Ten millilitres rumen liquor was conserved by adding 0.5 ml of 50% formic acid for analysis of NH_3-N by an automated colorimetric indophenol reaction (Logsdon 1960) and of volatile fatty acids (VFA) by gas chromatography (PYE-Unicam GCD), using a glass column packed with Chromosorb 101, 60-80 (Johns-Manville). The column temperature was 175°C and the carrier (N_2) flow rate was 75 ml/min. Detection was by hydrogen flame ionization and quantities were expressed as an integrator (HP3380A).

The duodenal digesta was collected on three consecutive days in each period at 09.00, 11.00, 13.00, 16.00, 18.00, 20.00 h by mounting the duodenal cannula with plastic bags. The pooled values represent the period. The pH was measured immediately and 10 ml fluid was conserved by adding 0.5 ml of 50% formic acid for NH_3-N analysis. Duodenal digesta was freeze-dried for chemical composition and for DAPA analysis which was carried out at the Central laboratory of the National Institute of Animal Science, Denmark.

The contents of Yb-Ac and Cr_2O_3 in the solution, duodenal digesta, faeces and urine were determined by atomic absorption (inductively coupled plasma, ICP).

Bacterial N in the duodenal flow was calculated by an assumed content of 41 mg DAPA per g of microbial-N (Hogan & Weston 1970) and by the difference between non-ammonia N and undegraded dietary N passing to the duodenum. Non-ammonia N entering the duodenum was corrected by 0.27% of the DM in the duodenal digesta for endogenous N (Van't Klooster & Rogers 1969). The amount of undegraded protein in each diet was calculated from the disappearance of N from the nylon bags of each feedstuff (Xu & Sundstøl 1991). The rumen outflow rate used in the calculation was 8% per h in accordance with Ilvelplund & Madsen (1985).

Total digested carbohydrates and carbohydrates digested in the rumen were calculated as digested CF plus digested NFE. The effects of the diets, the cows and the periods were assessed by the analysis of variance, using the general linear models (SAS 1985). Statistical differences between means were determined by Duncan's test at the 5% level (Snedecor & Cochran 1969).

RESULTS

The chemical compositions of dip-treated straw with or without urea, fish meal, barley meal and oat meal in Expts 1 and 2 are given in Table 2. The barley straw

Table 2. Chemical composition of the feeds

Feeds	DM%	In dry matter (g / kg)							
		ASH	CP	EE	CF	NFE	HEMIC	CEL	LIG
Expt 1									
Barley straw	86.5	58	47	20	423	452	338	412	45
Dip-treated straw									
without urea	24.3	136	49	14	412	389	193	378	35
with urea	26.7	135	124	15	412	389	197	364	35
Fish meal	92.5	124	743	125	-	8	-	-	-
Barley meal	88.0	24	125	21	48	782	205	42	6
Oat meal	91.1	30	121	50	103	696	192	104	21
Expt 2									
Barley straw	52.4	53	48	18	441	440	380	414	42
Dip-treated straw									
without urea	23.5	133	38	16	396	417	194	290	25
with urea	23.1	125	136	15	407	415	199	406	23
Fish meal	92.8	122	727	125	-	26	-	-	-
Barley meal	88.5	24	120	25	62	769	183	55	3
Oat meal	89.2	26	116	43	92	723	154	86	12

CP = Crude protein (N*6.25); EE = Ether extract;
CF = Crude fibre; NFE = Nitrogen free extract;
HEMIC = Hemicellulose; CEL = Cellulose; LIG = Lignin.

used in Expt 2 was treated with NaOH solution shortly after the barley was harvested. The DM content was therefore lower than that of the straw used in Expt 1, which was left in the field for one week of drying before being baled and treated with NaOH solution.

The increase in the ash and water contents of dip-treated straw was brought about by soaking the straw in the NaOH solution. The CP equivalent (N*6.25) was increased from 4-5% to 12-13% by adding urea to the NaOH solution.

In order to study the effect of NaOH treatment on the cell wall composition of barley straw, untreated straw was included in the studies. The hemicellulose content was reduced considerably in both experiments, while the reductions in cellulose and lignin content caused by NaOH treatment were relatively small. The lowest cellulose content for dip-treated

Table 3. Digestibility of diets based on dip-treated straw barley and oats supplemented with urea (Diet A) or fish meal (Diet B) (± SD)

	Expt 1		Expt 2	
	Diet A	Diet B	Diet A	Diet B
Dry matter	69.3 ± 1.2	68.5 ± 0.5	72.8 ± 3.8	71.0 ± 2.1
Organic matter	69.6 ± 1.5	69.3 ± 0.4	73.6 ± 3.7	72.9 ± 1.3
Crude protein	60.0 ± 1.2	60.8 ± 2.2	66.3 ± 5.0	62.8 ± 1.4
Ether extract	69.6 ± 3.0	78.3 ± 6.5	70.1 ± 7.7	69.6 ± 3.1
Crude fibre	63.2 ± 1.3	61.5 ± 9.4	72.3 ± 5.8	67.3 ± 5.0
N-free extract	75.1 ± 1.5	74.0 ± 3.4	76.2 ± 4.0	77.4 ± 1.9
Energy (MJ)	66.9 ± 2.1	65.7 ± 1.5	74.3 ± 4.1	68.4 ± 8.0
Hemicellulose	66.5 ± 1.2	64.9 ± 3.8	66.7 ± 7.7	64.4 ± 2.7
Cellulose	65.2 ± 1.3	60.0 ± 3.9	67.6 ± 8.8	58.2 ± 6.4
Lignin	22.8 ± 2.0	19.3 ± 9.5	18.1 ± 9.9	--
Number of observations:	2	2	5	4

straw without urea in Expt 2 was probably due to a technical error. The digestion coefficients of diets A and B are given in Table 3.

The digestibility values for DM, OM and CP in Expt 1 were similar for the two diets, while in Expt 2 slightly higher values were found for diet A than for diet B. Supplementation of fish meal to dip-treated straw resulted in increased digestibility of ether extract (EE) (diet B) in Expt 1. In both experiments the digestibility of CF and energy was higher for dip-treated straw with urea than for dip-treated straw supplemented with fish meal. The differences did not reach the level of statistical significance within the experiments, however. The digestibility of hemicellulose and cellulose followed the same trend.

The nitrogen balance for cows offered dip-treated straw and concentrates supplemented with urea or fish meal is given in Table 4.

Table 4. Nitrogen digestion and retention (g/d) of the cows fed dip-treated straw supplemented with urea (Diet A) or fish meal (Diet B) (±SD)

	Expt 1		Expt 2	
	Diet A	Diet B	Diet A	Diet B
Daily N intake	264.9±0.0	264.3±1.9	264.8±1.7	252.5±3.9
N in faeces	104.5±0.1	103.0±3.4	86.3±11.5	98.1±3.7
N in urine	46.8±17.9	31.4±4.0	76.9[a]±23.6	59.0[b]±26.5
N retention	113.7±17.8	129.8±5.4	101.7±26.7	95.4±28.0
Utilization of N, %	42.9±6.7	49.1±2.4	38.4±10.3	37.8±11.34
Number of observations:	2	2	5	4

Means with different superscripts within experiments are significantly different ($p<0.05$).

The amounts of N in diets A and B were the same in Expt 1, while in Expt 2 the intake of N was lower in diet B than in diet A because one of the cows did not like the fish meal. In Expt 1 equal amounts of faecal N were observed for the two diets, but in Expt 2 faecal N output was higher for the diet supplemented with fish meal. In both experiments the N excretion in urine was markedly increased when the cows were fed dip-treated straw with urea compared with cows fed treated straw supplemented with fish meal. The differences reached the significant level in Expt 2 ($p<0.05$). Part of this difference can be explained by the lower N intake for diet B. The utilization of N expressed as retained N in percentage of N intake was slightly higher for cows fed treated straw with fish meal in Expt 1, and was nearly the same for the two diets in Expt 2.

The mean values for pH and concentrations of ammonia-N in the rumen fluid and duodenal digesta and VFA in the rumen fluid are given in Table 5. The total VFA (mMol/l) in the rumen fluid was increased when the cows were fed dip-treated straw with urea compared with cows fed treated straw with fish meal in both experiments. The proportions of acetic, propionic and butyric acids (Mol%) were similar for the two diets in each experiment. Supplementation with fish meal seemed to give slightly higher proportions of isobutyric, isovaleric and valeric acids in both experiments.

In both experiments the mean rumen fluid pH of the cows fed dip-treated straw with urea was 0.1 units lower than the pH of the cows fed treated straw with fish meal. This may be related to the high VFA production in diet A. The average ammonia-N (mg/l) in the rumen fluid was markedly increased for the cows fed

Table 5. Concentrations of volatile fatty acids (VFA) in the rumen fluid and ammonia-N and H_3O^+ (pH) in the rumen and duodenal fluid of the cows fed straw/concentrate diets supplemented with urea (Diet A) or fish meal (Diet B)

	Expt 1		Expt 2	
	Diet A	Diet B	Diet A	Diet B
In rumen fluid:				
Total VFA, mMo/l	97.8	93.2	112.2	106.8
Individual VFA, Mol%:				
Acetic acid	67.0	67.5	66.3	64.9
Propionic acid	21.6	20.7	19.5	20.4
Isobutyric acid	0.6	0.7	0.8	1.0
Butyric acid	9.0	8.8	11.6	11.6
Isovaleric acid	0.7	0.9	1.0	1.1
Valeric acid	1.3	1.4	1.0	1.1
pH	6.4	6.5	6.3	6.4
Ammonia-N, mg/l	57.1	22.1	52.8[a]	20.2[b]
In duodenal digesta:				
pH	3.6	3.6	3.8	3.6
Ammonia-N, mg/l	34.2	22.7	35.1a	27.7[b]

Superscripts see Table 4.

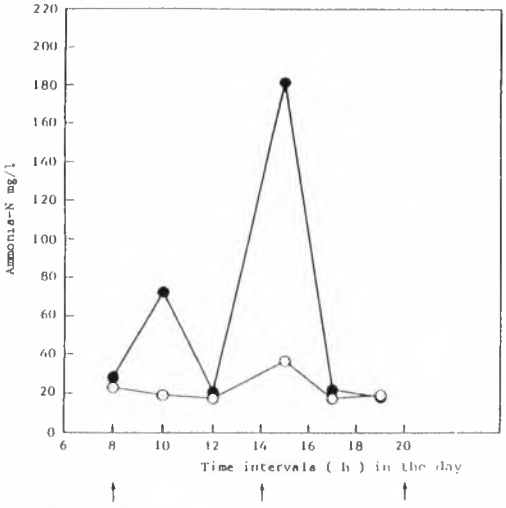

Figure 1. The changes of NH_3-N concentration in the rumen in Expt 1.
Feeding time ↑
NH_3-N concentration in diet A. Dip-treated straw with urea ●
NH_3-N concentration in diet: Dip-treated straw with fish meal o

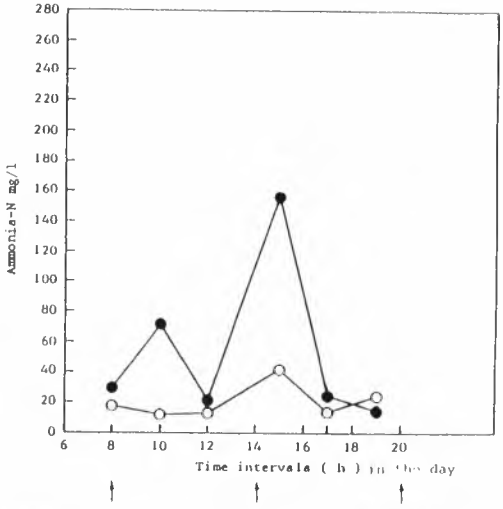

Figure 2. The changes of NH_3-N concentration in the rumen in Expt 1.
For identification of treatments, see Figure 1

on diet A. The differences reached the significance level in Expt 2 ($p<0.05$). The variation in NH_3-N with time is shown in Figures 1 and 2.

The pH of the duodenal digesta was constant in this study with the exception of the pH on diet A in Expt 2, which was 0.2 units higher than the others. The

Table 6. The composition of the duodenal digesta from cows fed a straw/concentrate diet supplemented with either urea (Diet A) or fish meal (Diet B)

	Expt 1		Expt 2	
	Diet A	Diet B	Diet A	Diet B
DM%	4.05	4.15	3.90	4.05
In dry matter, g/kg:				
Ash	194	194	198	193
Organic matter	806	806	802	807
Ether extract	45	49	49	53
Crude fibre	115	100	72	81
N-free extract	412	410	433	431
Crude protein	234	247	248	242
True protein	174	179	166	176
True protein in % of crude protein	74	73	67[b]	73[a]
Hemicellulose	93	85	66	74
Cellulose	108	98	75	94
Lignin	14	16	10	11
Number of observations:	2	2	5	4

Superscripts see Table 4.

ammonia-N in the duodenal digesta followed the same pattern as that in the rumen in which a higher content of ammonia-N was found for the cows fed dip-treated straw with urea than the cows fed treated straw with fish meal and significant differences were observed in Expt 2 ($p < 0.05$). The chemical composition of the duodenal digesta from the cows fed the two diets is given in Table 6.

In both experiments the contents of DM and OM in the duodenal digesta were similar for the cows fed treated straw and concentrates supplemented with either urea or fish meal. The content of EE in the duodenal digesta was increased by feeding a straw/concentrate diet supplemented with fish meal, which also gave a slightly higher content of true protein in the digesta. The CP (N*6.25) content in the duodenal digesta was also higher for the diet supplemented with fish meal in Expt 1, whereas no such difference was observed in Expt 2. The proportion of true protein in the total CP (N*6.25) was the same for the two diets in Expt 1, while in Expt 2 it was significantly higher for the diet with fish meal than for the diet with urea ($p < 0.05$).

Table 7 gives the amount of microbial N estimated from either the content of microbial marker (DAPA) in the duodenal digesta or by difference expressed per unit of total digested carbohydrates or carbohydrates digested in the rumen.

There was no significant difference in the content of DAPA when the cows were fed treated straw plus concentrates supplemented with either urea or fish meal. The duodenal digesta estimated by Cr_2O_3 was generally higher than that estimated from Yb-Ac (8-11% in Expt 1 and 6-17% in Expt 2). The estimated amount of duodenal digesta (kg DM/d) was higher for cows fed roughage supplemented with fish meal than for cows fed roughage with urea, i.e. 5-8% higher when estimated on the basis of Cr_2O_3 and Yb-Ac respectively in Expt 1, and 10-21% in Expt 2. The difference reached the significance level in Expt 2 ($p < 0.05$) estimated from the Cr_2O_3 concentration. Bacterial N in the duodenal flow, estimated by both DAPA and difference, showed essentially the same degree of difference between Cr_2O_3 and Yb-Ac as DM. Bacterial N estimated by difference seemed to narrow the difference between the two diets (except for diet A in Expt 1).

The total digested carbohydrates for

Table 7. The amount of microbial N passing to the duodenum estimated either by the content of diaminopimelic acid (DAPA) in the duodenal flow or as the difference between non-ammonia and undegraded dietary N entering the duodenum per unit of total digested carbohydrates or carbohydrates digested in the rumen with two different markers Cr_2O_3 and Yb-Ac

	Expt 1		Expt 2	
	Diet A with urea	Diet B with fish meal	Diet A with urea	Diet B with fish meal
Estimation by DAPA:				
DAPA, g/kg DM	1.28	1.14	1.17	1.12
Duodenal digesta, kg DM/d				
from Cr_2O_3,	8.53	9.23	8.37[b]	10.15[a]
from Yb-Ac,	7.86	8.27	7.86	8.62
Bacterial N in duodenal digesta, g/d				
from Cr_2O_3,	237.2	255.9	237.3	276.9
from Yb-Ac,	245.5	225.5	221.0	234.5
Total digested carbohydrates, kg DM/d	7.81	7.34	7.96	8.08
Digested carbohydrates in rumen , kg DM/d				
from Cr_2O_3,	4.73	3.66	4.54	3.58
from Yb-Ac,	5.20	4.37	4.89	4.62
Bacterial N g/total digested carbohydrates,kg DM				
from Cr_2O_3,	29.95	34.88	30.02	34.31
from Yb-Ac,	31.48	30.72	28.07	29.01
mean	30.72	32.80	29.05	31.66
Bacterial N g/rumen digested carbohydrates, kg DM				
from Cr_2O_3,	50.14	70.59	54.94	78.52
from Yb-Ac,	47.25	53.23	49.10	51.98
mean	48.70	61.91	52.02	65.25
Estimation by difference:				
Bacterial N in duodenal digesta, g/d				
from Cr_2O_3,	241.0	248.2	255.7	283.7
from Yb-Ac,	217.0	213.1	235.6	229.6
Bacterial N g/total digested carbohydrates,kg DM				
from Cr_2O_3,	30.43	33.82	32.39	35.12
from Yb-Ac,	27.78	29.02	29.97	28.36
mean	28.94	31.42	31.18	31.74
Bacterial N g/rumen digested carbohydrates, kg DM				
from Cr_2O_3,	50.95	68.16	59.56	80.93
from Yb-Ac,	41.72	51.57	52.93	51.28
mean	46.23	59.86	56.24	66.10

Superscripts see Table 4.

the two diets was nearly the same within experiments. The rumen-digested carbohydrates were estimated lower by Cr_2O_3 than by Yb-Ac because of a correspondingly higher amount of digesta in the duodenum.

Bacterial N, expressed per kg DM of total digested carbohydrates, was similarly estimated by either DAPA or difference. A slightly higher amount was observed for diet B supplemented with fish meal than for diet A supplemented with urea in both experiments, regardless of marker.

When the production of bacterial N was expressed per unit of rumen-digested carbohydrates, the difference between Cr_2O_3 and Yb-Ac and between the two diets was greater than when it was calculated per unit of total digested carbohydrates. This can be explained by the amount of different duodenal digesta caused differences in the concentrations of Cr_2O_3 and Yb-Ac in the duodenal flow,

Table 8. The concentrations of urea and minerals in blood from cows fed dip-treated straw with urea (Diet A) or fish meal (Diet B) (mMol/l, ± SD)

	Expt 1		Expt 2	
	Diet A	Diet B	Diet A	Diet B
Urea	1.57 ± 0.46	1.52 ± 0.74	2.34a ± 0.59	1.86b ± 0.51
Magnesium	0.85 ± 0.15	0.84 ± 0.08	0.96 ± 0.11	0.97 ± 0.06
Calcium	2.18 ± 0.07	2.20 ± 0.16	2.42 ± 0.18	2.49 ± 0.11
Sodium	132.00 ± 2.12	133.75 ± 1.08	112.35 ± 15.9	110.20 ± 18.1
Potassium	3.41 ± 0.49	3.58 ± 0.23	3.21 ± 0.49	3.15 ± 0.60

Superscripts see Table 4.

which again resulted in differences in rumen-digested carbohydrates. Table 8 gives the concentrations of urea and certain minerals in the blood.

A higher urea content in the blood was obtained when the cows were fed dip-treated straw with urea than when fed treated straw with fish meal. The difference was significant in Expt 2 ($p < 0.05$) only. The concentrations of magnesium, calcium, sodium and potassium did not give rise to any significant difference for the two diets in any of the experiments.

DISCUSSION

Barley straw treated with NaOH solution by the dip treatment method (Sundstøl 1981) results in increased ash content of treated straw. The CP content may be enhanced by mixing urea into the NaOH solution (Xu 1986). The fraction of cell wall content (NDF) in straw is reduced by NaOH treatment because of solubilization of hemicellulose (Ololade et al. 1970). From a study on the effect of NaOH treatment of barley straw, Kristensen et al.(1977) concluded that about one-third of the reduction of NDF is caused by increased soluble ash content in the DM of straw and two-thirds of the reduction is due to increased solubility of lignin and hemicellulose.

Sodium hydroxide may exert its effect through delignification of the cell wall fraction (Tarkow & Feist 1979, Wignjosoesastro & Young 1982), rendering treated straw more readily available to the rumen microorganisms. Lindberg et al.(1984) observed that xylans are partly translocated during aqueous NaOH treatment to a position in the straw cell walls where they are more available to ruminal digestion.

The digestibility of dip-treated straw in the present study was in line with the findings of Wanapat et al. (1985) which showed that the organic matter digestibility (OMD) of dip-treated straw or dip-treated straw with urea can be elevated to 70%, about 20-24 units of improvement compared with straw without treatment. Digestibility of hemicellulose in straw higher than that in the present study was reported by Kristensen et al. (1977) when the cows were fed a ration containing 50% NaOH-treated straw (5% NaOH). The digestibilities of hemicellulose and cellulose were 89% and 63%, respectively. A high EE content in the duodenal digesta for the diet containing treated straw/concentrates supplemented with fish meal in Expt 1 (Table 6) compared with that supplemented with urea is most likely because of the 8 g extra fat which was added to diet B through fish meal (Table 3), i.e. less effect of metabolic faecal fat.

A higher protein content in the duodenal digesta of diet B than in that of diet A can probably be explained by the higher amount of rumen undegradable protein from fish meal.

The utilization of urea is greatly in-

fluenced by the amounts of available carbohydrates in the diet. The combination of NaOH-treated straw with urea gives more satisfactory results, as can be seen in the feeding experiments with dairy cows and heifers fed dip-treated straw with urea or soybean meal as compared with grass silage, as reported by Randby & Xu (1988).

The high rumen ammonia-N and the correspondingly high urea concentration in the blood when supplementing with urea in the present experiments resulted in losses of excess ammonia-N through urine. This was in agreement with Bartly & Deyoe (1981). Smith (1975) reported that a high concentration of ammonia in the rumen does not inhibit bacterial growth.

The pattern of VFA in the rumen liquor, expressed as molar proportion (in percent), provides a relatively simple way of characterizing the fermentation of the ration. The proportions of acetic, propionic and butyric acids (Table 5) were similar to those obtained by feeding dairy cows with 60% hay plus 40% concentrate (Bondi 1987). The VFA production in the rumen of cows fed dip-treated straw with urea or soybean meal was almost the same when compared with grass silage (Xu et al. 1991).

A higher proportion of acetic acid and a higher acetic: propionic acid ratio were reported by Kristensen et al.(1977) when cows were offered 50% NaOH-treated straw and 46% rolled barley than when they were fed 46% dried beet pulp molasses.

The validity of DAPA as a microbial marker for estimating the microbial N synthesis in the rumen has been discussed. The range from 34 to 75 mg DAPA per g bacterial N is reported (Smith 1975).

Hvelplund & Madsen (1985) used 35.3 mg DAPA per g bacterial N and they found that the microbial N (g/d) estimated by DAPA was 15% higher than that estimated by difference. In the present study similar results were obtained as estimated by the two methods.

The average of 29-33 g bacterial N, estimated by DAPA and by difference, per kg total digested carbohydrates in the present experiment agreed well with the suggested value of 29 g by the Nordic protein evaluation system (Madsen 1985).

The value for production of microbial N, expressed as g per kg rumen digested carbohydrate, for the cows fed treated straw/concentrate supplemented with urea was close to the values reported by Hvelplund & Madsen (1985), while for the diet containing treated straw/concentrate supplemented with fish meal the production value was 10-15 g higher. This may be explained by the lower content of digestible carbohydrates in the rumen for diet B with fish meal. Supplementation of fish meal did not seem to improve the bacterial N synthesis effectively in the present study, which is in agreement with Harstad & Vik-Mo (1985).

The urea concentration in the blood was markedly lower in the present study (1.5-2.3 mMol/l) than in a previous experiment (5-6 mMol/l) (Xu et al. 1991). Kaufmann (1979) indicated that an increased plasma urea content reflected the relatively lower energy level in the rumen. Supplementation of barley meal/oat meal and small amounts of molasses to dip-treated straw in the present experiment probably provided better conditions for urea utilization in the rumen than in the previous experiment in which cows were fed smaller amounts of barley meal. Many reports elsewhere indicate that NaOH-treated straw supplemented with molasses seems to have a beneficial effect on urea utilization in the rumen (Ali & Sørensen 1979, Gihad 1979, Kategile 1979, Borhami et al. 1983).

The antagonism between sodium and magnesium in the blood seems to occur when cows are offered a high amount of NaOH-treated straw daily (Moseley & Jones 1974, Arnason 1980, Randby & Xu

1988). The magnesium concentration in the blood in the previous experiment (Xu et al. 1991) was significantly lower when dairy cows were fed dip-treated straw with urea or soybean meal compared with the values for cows fed grass silage. Most of the dietary sodium, but not all, was excreted in the urine when the animals were fed dip-treated straw. This was in agreement with Kristensen et al. (1977). Since a negative balance of magnesium was observed in this study the supplementation of minerals, magnesium in particular, needs attention when high proportions of NaOH-treated straw are being used in the diets for farm animals.

SUMMARY

The digestibility and duodenal digesta flow in dairy cows fed dip-treated straw and concentrates supplemented with urea (diet A) or fish meal (diet B) were determined in two experiments.

Two cows in late lactation were used in the first experiment and another two cows in Expt 2 (the third was a reserve). The cows were surgically equipped with permanent rumen and duodenal cannulas.

Diets A and B were formulated so as to be isonitrogenous. The rations were divided into four equal parts and were fed at 08.00 and 14.00 h by hand, and at 20.00 and 02.00 h by auto-feeder.

The OMD values for diet A (with urea) and diet B (with fish meal) were 69.6, 69.3% in Expt 1 and 73.6, 72.9% in Expt 2, respectively.

The digestibility of N*6.25 was almost identical for the two diets(60.0% and 60.8%) in Expt 1, whereas it was slightly higher for diet A in Expt 2 (66.3% vs. 62.8%).

The digestibility of CF in both experiments was slightly higher for the cows fed diet A (with urea) compared with those fed diet B (with fish meal), (63.1% vs. 61.5% in Expt 1 and 72.3% vs. 67.3% in Expt 2). The digestibility of hemicellulose and cellulose followed the same pattern as CF.

The excretion of N in the urine tended to be higher for the cows fed the diet with urea in both experiments, the difference reaching the significance level in Expt 2 (76.9 g/d vs. 59.0 g/d, $p<0.05$), which was partly due to the lower intake of N for the cow fed the diet with fish meal.

The total VFA in the rumen liquor was slightly higher for the cows fed treated straw/concentrate with urea than for the cows fed treated straw/concentrate with fish meal. The differences in individual VFA between the two diets were fairly small in both experiments.

The ammonia-N concentrations (mMol/l) in the rumen and duodenum were higher when the cows were given urea compared with fish meal in both experiments. Significant differences in the rumen (54.6 vs. 17.9 mMol/l) as well as in the duodenum (35.1 vs. 27.7 mMol/l) were found in Expt 2 ($p<0.05$).

The chemical composition of the duodenal digesta showed no significant difference between urea and fish meal as supplements to a diet based on dip-treated straw and concentrates. Moreover, the content of DAPA in the duodenal digesta was nearly the same for the two diets.

The flow of digesta to the duodenum was estimated by the use of Cr_2O_3 and Yb-Ac as markers. The concentration of DAPA in the duodenal digesta was similar for dip-treated straw/concentrate supplemented with either urea or fish meal. Supplementation of fish meal had no significant effect on bacterial N synthesis in the rumen in the present study. Bacterial N, 29-33 g per kg of total digested carbohydrates estimated by either DAPA or difference, matched well with the Nordic protein evaluation system (29 g).

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Rumen degradation of dip-treated barley straw

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Xu, S. & F. Sundstøl 1991. Rumen degradation of dip-treated barley straw. Norwegian Journal of Agricultural Sciences 5: 235-244. ISSN 0801-5341.

Two experiments were carried out with the objective of studying the effect of dip treatment on the degradability of barley straw in the rumen of cows fed a diet based on dip-treated straw/concentrates. The degradability of dip-treated straw with or without urea was markedly increased compared with that of untreated straw.

Key words: Degradability of untreated, dip-treated straw, fistulated cows, urea.

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The limitations for an extended use of straw as feed for ruminants are the low content of available energy and protein and low rate of degradation in the rumen, causing a relatively low voluntary feed intake (Ørskov 1985).

The digestibility of straw and voluntary intake of straw by animals can be increased by various chemical, physical and microbial treatments. In particular, treatment with sodium hydroxide solution has been extensively studied and used in Norway for many years (Sundstøl 1988).

The nylon bag technique has been applied widely to evaluate the degradability of roughages incubated in the rumen of animals (Mehrez & Ørskov 1977, Ørskov et al. 1980). The mathematical model developed by Ørskov and McDonald (1979) is used to describe the degradation characteristics off testing feed (Sauvant et al. 1985, Vik-Mo & Lindberg 1985, Walli et al. 1988, Vik-Mo 1989).

The objectives of the present experiments were to study the degradability of NaOH-treated straw with or without urea compared with untreated straw, and the degradability of concentrates incubated in the rumen of cows fed straw diets supplemented with either urea or fish meal.

MATERIALS AND METHODS

Preparation of samples for in sacco:
Samples were obtained of untreated straw, dip-treated straw with or without urea, barley meal, oat meal and fish meal. The composition of feeds was analysed by standard procedures (AOAC 1980) at the Central Analytical Labora-

tory, Agricultural University of Norway. The method of NaOH treatment of barley straw used in the study was the dip treatment method described by Sundstøl (1981). Dip-treated straw with urea was obtained by mixing urea into the NaOH solution (11 g/l). The samples of dip-treated straw for incubation were freeze-dried (-60°C). All samples were ground to pass through a 2.0 mm screen and 2.000 g, precisely weighed, was placed in each bag; the bags were made from precision woven cloth (ZBF. AG, CH-8802 Rushlikon) with 36 µm pore size, sewn to 50 * 100 mm inner size and glued at the edges over the stitches. Different samples were incubated in sacco in the rumen of cows for successive intervals in order to assess the disappearance of dry matter (DM). The samples were incubated in two fistulated dairy cows with six replicates in order to obtain enough residue for analysis. Incubations started at the morning feeding of cows and lasted for 2, 4, 8, 16, 24 and 48 h for concentrates. For roughages the incubation period was extended to 72 and 96 h. After incubation, the bags were rinsed in tap water and washed for about 30 min in a washing machine. They were then dried at 45°C for 48 h and weighed. For each sample and incubation time the remaining material of the replicates from the two cows was composited for chemical analysis.

Cows and feeding:
Two experiments were carried out in the present study, each with two lactating cows equipped with a rumen fistula, inner diameter 120 mm. In Expt 1 each cow received the two diets in two consecutive periods (changeover 2 * 2), whereas in Expt 2 the two diets were compared in the two cows for three periods (double reversal).

The cows were fed to the level of production plus maintenance for both energy and crude protein (CP). The daily ration was divided into four equal parts and given at 08.00 and 14.00 h by hand, and at 20.00 and 02.00 h by auto-feeder.
The diets consisted of concentrates and dip-treated straw plus either urea (diet A) or fish meal (diet B) (Table 1). The proportions between urea and fish meal (high degradability 70%) were regulated in order to make the diets isonitrogenous. The cows were given 100 g of a mineral mixture daily (Mg-enriched blend, A/S Norsk mineralnæring, Oslo). The cow on diet A was given 70 g $MgSO_4$ daily (assuming N:S as 10:1, according to Silva & Ørskov 1988a).

Sample analysis and calculation:
The samples of the feeds given in Table 1 were analysed for the content of DM, ash, crude fibre (CF), ether extract (EE) and nitrogen (N) (AOAC 1980). The nitrogen

Table 1. Diets fed to cows in Expts 1 and 2

	Diet A			Diet B		
	DM kg/d	Feed units	Dcp g	DM kg/d	Feed units	Dcp g
Dip-treates straw:						
with urea	6.2	4.0	575	-	-	-
without urea	-	-	-	6.2	4.0	-
Fish meal	-	-	-	0.757	0.97	575
Barley meal	3.0	3.5	282	3.0	3.5	284
Oat meal	3.1	4.0	280	3.1	4.0	280
Molasses	0.239	0.2	5.5	0.239	0.2	5.5

Dcp = Digestible crude protein

free extract (NFE) was calculated by difference.

The mean disappearances of DM from two periods in Expt 1 and from three periods in Expt 2 were calculated. The effects of the diets, cows and periods in Expts 1 and 2 were assessed by the analysis of variance, using the general linear models (GLM) (SAS 1985). Statistical differences between means were determined by Duncan's test at the 5% level (Snedecor & Cochran 1969).

Losses of materials over time were estimated according to Ørskov & McDonald (1979) by calculating the constants a, b and c in the equation:

$$P = a + b(1 - e^{-ct})$$

where P is the actual degradation after time t (h), a is the intercept at time zero (the immediately soluble material), b is the potentially fermentable material, and c is the degradation rate of the b fraction. Constants were obtained by SAS program (Proc NLIN 1985).

Effective protein degradability (EPD) in the rumen was estimated using the equation:

$$EPD = a + b * c / (c + k)$$

(Ørskov & McDonald 1979)

Where k is interpreted as the rate constant or fractional rate at which particles pass from the rumen to the abomasum.

RESULTS

The chemical composition of the feeds used in Expts 1 and 2 is given in Table 2.

The barley straw used in Expt 2 was treated with NaOH solution shortly after the barley was harvested; the DM content was lower than that of Expt 1 in which straw was left in the field for one week of drying before being baled and treated.

The ash content of the dip-treated straw was more than twice that of untreated straw and supplementation of urea to the dip-treated straw increased the nitrogen (N) content by 153 and 258% in the two experiments, respectively.

The DM losses of the different feeds at progressive times in the rumen in Expts 1 and 2 are shown in Figures 1 to 4. Degradation of the roughages increased

Table 2. Chemical composition of the feeds

Feeds	DM%	Content in DM, g/kg				
		CP	EE	CF	NFE	Ash
Expt 1						
Untreated straw:	86.5	47	20	423	452	58
Dip-treated straw:						
without urea	24.3	49	14	412	389	136
with urea	26.7	124[1)]	15	412	389	135
Fish meal	92.5	743	125	-	8	124
Barley meal	88.0	125	21	48	782	24
Oat meal	91.1	121	50	103	696	30
Expt 2						
Untreated straw	52.4	48	18	441	440	53
Dip.treated straw:						
without urea	23.5	38	16	396	417	133
with urea	23.1	136[1)]	15	407	415	125
Fish meal	92.8	727	125	-	26	122
Barley meal	88.5	120	25	62	769	24
Oat meal	89.2	116	43	92	723	26

CP = Crude protein, EE = Ether extract, CF = Crude fibre, NFE = Nitrogen free extract.
[1)] Protein equivalent.

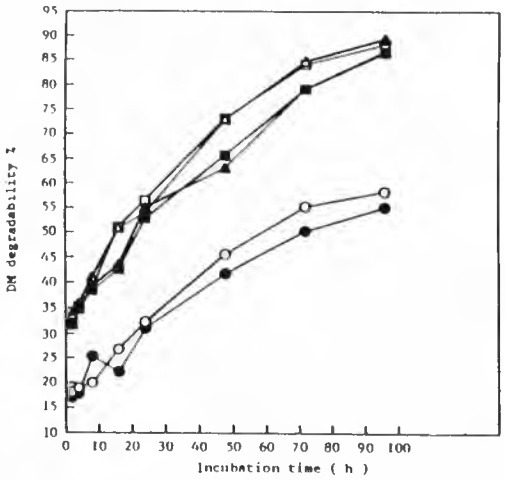

Figure 1. DM degradability of roughages in Expt 1
Untreated straw in diet A●
Untreated straw in diet B ○
Dip-treated straw in diet A ■
Dip-treated straw in diet B □
Dip-treated straw with urea in diet A ▲
Dip-treated straw with urea in diet B △

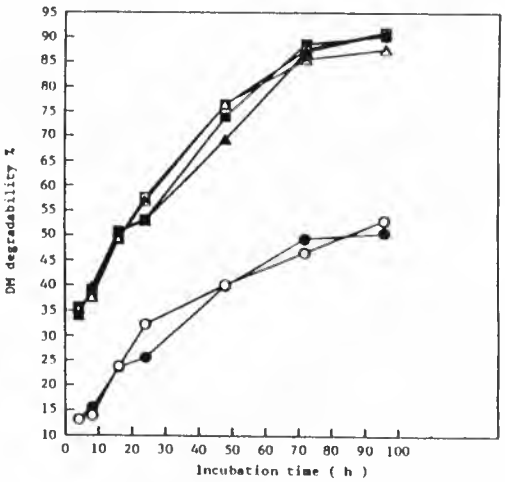

Figure 2. DM degradability of roughages in Expt 2.
For identification of trestments, see Figure 1

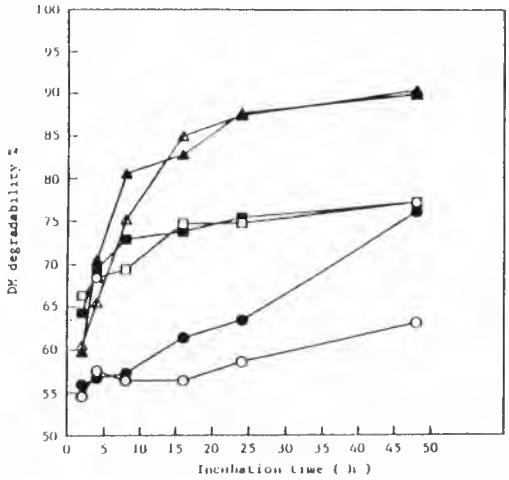

Figure 3. DM degradability of concentrates in Expt 1.
Fish meal in diet A ●
Fish meal in diet B ○
Oat meal in diet A ■
Oat meal in diet B □
Barley meal in diet A ▲
Barley meal in diet B △

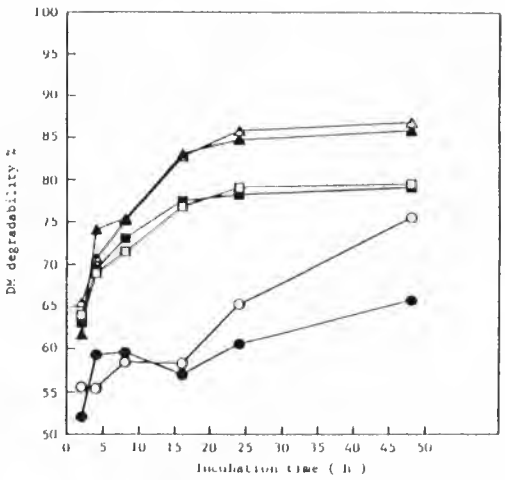

Figure 4. DM degradability of concentrates in Expt 2
For identification of treatments, see Figure 3

Table 3. The DM degradability of the roughages at 48 h and the constants fitting the equation $P = a + b(1 - e^{-ct})$

Feeds	In vivo DM and (OM) digestibility	Diets	Degradability at 48 h	a	b	c	Asymptote a+b
Expt 1							
Untreated straw		A	41.8	16.0	58.6	0.0118	74.6
		B	45.6	15.0	58.3	0.0152	73.3
Dip-treated straw without urea:							
	68.5 (69.3)	A	65.7	29.3	70.7	0.0162	100.0
		B	73.2	29.4	67.1	0.0224	96.5
Dip-treated straw with urea:							
	69.3 (69.6)	A	63.1	30.0	70.0	0.0159	100.0
		B	73.0	30.8	69.2	0.0196	100.0
Expt 2							
Untreated straw		A	39.9	16.4	-	-	-[1]
		B	40.2	7.6	48.5	0.0251	56.1
Dip-trested straw without urea:							
	71.0 (72.9)	A	73.9	27.9	72.1	0.0217	100.0
		B	76.5	27.3	72.7	0.0230	100.0
Dip-treated straw with urea:							
	72.8 (73.6)	A	69.3	28.5	71.5	0.0202	100.0
		B	76.6	26.6	68.5	0.0258	94.8

[1] The incubation period of 96 h was too short for the asymptote to be reached

at a diminishing rate and was considerably lower for untreated straw than for NaOH-treated straw. The degradability of straw was apparently lower for diet A than for diet B in Expt 1. The degradation of concentrates was not affected by the different basal diets in Expts 1 and 2. Barley meal degraded to a great extent, followed by oat meal and then fish meal.

The in sacco degradability values of untreated straw and dip-treated straw with and without urea are given in Table 3. The losses of DM from dip-treated straw at 48 h were compared with in vivo DM and organic matter (OM) digestibilities of the same feeds. For diet A (treated straw with urea), the in sacco losses (48 h) were lower, whereas in diet B (treated straw supplemented with fish meal), they were slightly higher than those measured in vivo. The average DM losses of dip-treated straw with or without urea, regardless of basal diets, matched well with the in vivo OM digestibility. The maximum deviation between the DM losses at 48 h and in vivo OM digestibility was 2 units in Expt 2. In Expt 1 the difference was less.

The soluble fraction (a) of dip-treated straw was increased as compared with untreated straw and so was the potential of degradability (a+b). The rate constants (c) of degradable material were generally higher in Expt 2 than in Expt 1. The addition of urea during NaOH treatment of the straw had no influence on the in sacco degradability or the in vivo digestibility.

EPD was calculated using a series of assumed rumen flow rates (2-10% per h) to indicate the effect of retention time on EPD for different feeds. The results are shown in Figures 5 to 8. For roughages the EPD of untreated straw was almost unaffected by the rumen flow rate in both experiments (Figures 5 and 6) but the EPD values of dip-treated straw varied with different rumen flow rates from 2 to 10%. More CP was degraded at a low rumen flow rate and less at a high rate.

For concentrates the EPD values of

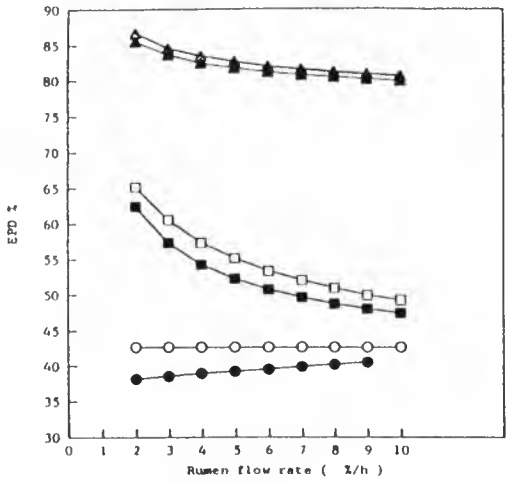

Figure 5. The EPD values of roughages in Expt 1
Untreated straw in diet A ●
Untreated straw in diet B ○
Dip-treated straw in diet A ■
Dip-treated straw in diet B □
Dip-treated straw with urea in diet A ▲
Dip-treated straw with urea in diet B △

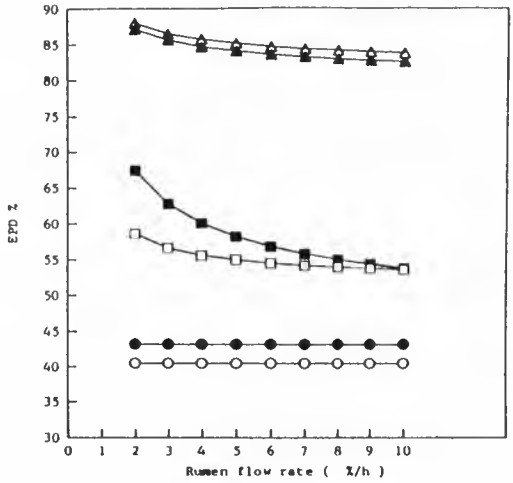

Figure 6. The EPD values of roughages in Expt 2.
For identification of treatments, see Figure 5

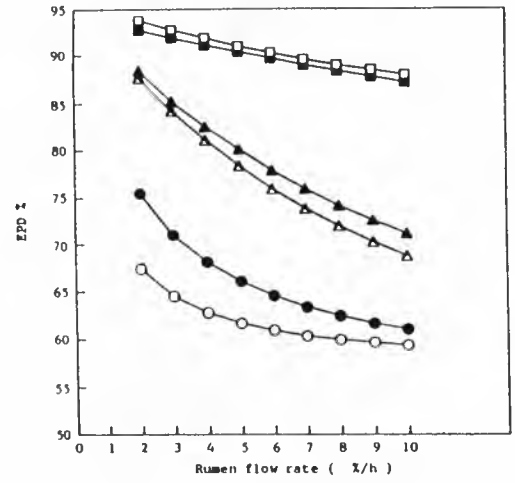

Figure 7. The EPD values of concentrates in Expt 1.
Fish meal in diet A ●
Fish meal in diet B ○
Oat meal in diet A ■
Oat meal in diet B □
Barley meal in diet A ▲
Barley meal in diet B △

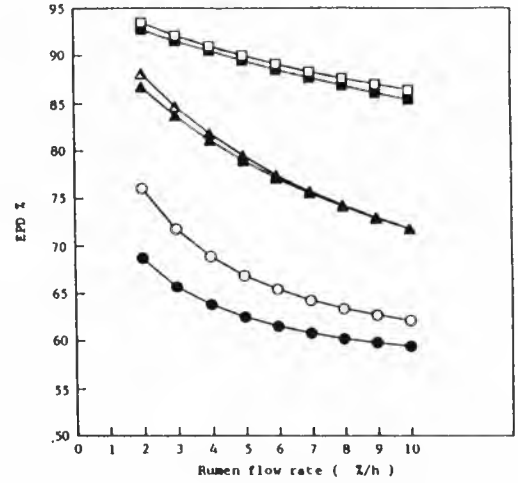

Figure 8. The EPD values of concentrates in Expt 2
For identification of treatments, see Figure 7

fish meal, oat meal, and barley meal followed a similar pattern in both experiments. The highest EPD value was found for barley meal followed by oat meal and fish meal at each assumed rumen flow rate (Figures 7 and 8).

DISCUSSION

Treatment of barley straw with a NaOH solution markedly increased its degradability in the rumen as shown clearly in the present study. There are many reports (Fernandez et al. 1972, Fahmy & Sundstøl 1984, Silva & Ørskov 1988b) indicating that alkali agents partially cleave the bonds between lignin and hemicellulose and make treated roughages available to the microorganisms in the reticulo-rumen.

Latham et al. (1979) found that for plant stems treated with alkali, which is a partial removal of lignin from the cell walls, the numbers of attached rumen bacteria increased tenfold.

The role of rumen anaerobic fungi in the digestion of poor quality forages has been recognized recently (Orpin 1983/84). It is assumed that fungi also break hemicellulose-lignin complexes so that plant structural components (cell walls) can be fermented by the rumen bacteria (Preston & Leng 1987). From sporangia on plant tissues to release of zoospores in the fungal life cycle, it takes about 24-32 hours (Joblin 1981, Bauchop 1983). Bird & Leng (1985) reported that the rate of disappearance of straw DM was increased by 6-10 units/24 h because of more zoospores in the rumen fluid. This supports the finding of the present study which show that the degradability of dip-treated straw with or without urea was markedly increased even after 24 h of incubation in the rumen. Barley meal, which has a higher degradability than oat meal (Figures 3 and 4), would be more suitable as a supplement to a diet containing urea as a source of nitrogen (Odle & Shaefer 1987).

Fahmy & Sundstøl (1984) found no effect of urea on in vitro digestibility of untreated straw, but found a dramatic effect of urea supplementation on the digestibility of dip-treated straw.

The optimum level of NH_3-N concentration in the rumen for the maximum rate of fermentation seems to vary. For instance, many in vitro experiments have shown that the NH_3-N concentration required for maximum microbial protein synthesis per unit of substrate fermented is approximately 50-60 mg/l rumen fluid (Allison 1970, Satter & Slyter 1974). The lowest value for 16 mg/l was reported by Nikolic et al. (1975). In vivo studies have shown that the corresponding NH_3-N concentration is 88-133 mg/l (Hume et al. 1970) or 235 mg/l, as reported by Mehrez et al. (1977). The high level of DM disappearance of untreated straw, dip-treated straw with or without urea obtained in these experiments does indicate that an ammonia-N concentration as low as 20-22 mg/l (see Xu & Sundstøl 1991) may be sufficient for normal degradation of roughages in the rumen. Maeng & Baldwin (1976) reported that the ATP yield was increased by about 34% when 25% of urea N in a purified diet was replaced by a mixture of amino acids. This observation was supported by Johnsen (1981) in an experiment with fish meal. In the present experiments the diurnal variations of NH_3-N concentration (see Xu & Sundstøl 1991) were always higher for the dip-treated straw with urea diet than for the dip-treated straw supplemented with fish meal diet. But the degradation of untreated straw and dip-treated straw with or without urea was generally lower than that with fish meal in Expt 1. In Expt 2. no such difference was found.

Sauvant et al.(1985) found that there was a strong correlation between the in sacco DM degradability at 48 h ruminal incubation (DMDG48) and the in vivo organic matter digestibility (OMD) of feeds ($r = 0.92$). The DMDG48 of straw has been used to predict its OMD (Bhargava

et al. 1988, Shand et al. 1988). In the present study the mean DMDG48 of dip-treated straw with or without urea gave a satisfactory prediction of the OMD according to the equation of Sauvant et al.(1985):

$$OMD = 20.0 + 0.68 * DMDG48$$

The application of the Ørskov/McDonald equation characterized the difference between untreated straw and dip-treated straw with or without urea and the variation in degradability due to the basal diets. Water soluble DM defined as (a), and potentially fermentable DM defined as (b) in the equation, were increased for dip-treated straw with or without urea compared with untreated straw. The (b) values were almost similar for roughages incubated in the A and B diets. But a slightly higher degradation rate (c) was found for the roughages incubated in the cows fed the B diet containing fish meal. The potential (maximum, a + b) degradability of dip-treated straw with or without urea was markedly high (100%) and was probably overestimated by the equation used.

Since the N content of untreated straw is very low, the EPD values at different assumed rumen flow rates did not change at all (Figures 5 and 6). Barrio et al. (1985) indicated that protein associated with the plant cell wall may only be released when the cell wall is digested. The results from the present study seemed to support this, as it can be seen that the EPD values of dip-treated straw at different assumed rumen outflow rates were much higher than those from untreated straw. Furthermore, EPD values of dip-treated straw were markedly improved by urea supplementation, as one would expect.

The ingredients of the basal diet have an effect on the nitrogen disappearance in the rumen. Ganev et al.(1979) reported that the rate of N disappearance was greater in an animal fed a roughage-based diet than in an animal fed a diet containing a high proportion of concentrates. Protein of vegetable origin degraded faster than protein of animal origin. This was observed in the present study (Figures 7 and 8), which simply indicated that the higher the rumen outflow rate, the less protein was degraded in the rumen and the more bypass protein that passed to the abomasum, although the EPD is closely correlated with the outflow rate which is influenced by several factors (Ørskov et al. 1981, Kristensen et al. 1982).

SUMMARY

The degradability of untreated straw, dip-treated (NaOH-treated) straw with or without urea, barley meal, oat meal and fish meal in the rumen of cows fed treated straw with urea (diet A) or treated straw supplemented with fish meal (diet B) was studied in two experiments.

Two cows fitted with a permanent rumen fistula were used in each experiment. Diet A (with urea) and diet B (with fish meal) were adjusted so as to be isonitrogenous. The rations were sufficient to meet the levels of production and maintenance of the cows and were divided into four equal parts and given at 08.00 and 14.00 h by hand, and at 20.00 and 02.00 h by auto-feeder.

The degradability of dip-treated straw with or without urea was markedly increased compared with that of untreated straw. Barley meal (DM) was highly degradable, followed by oat meal and fish meal.

The prediction of in vivo OMD from the values at 48 h incubation in the rumen gave very satisfactory results.

The equation developed by Ørskov/McDonald was used to describe the difference between untreated and dip-treated straw with or without urea.

The EPD of tested feeds was calculated with a range of assumed rumen outflow rates (2-10%/h). The EPD of untreated straw was not affected by rumen

outflow rates, but at different rumen outflow rates the EPD of treated straw with or without urea was changed. The EPD of concentrates varied with a series of assumed rumen outflow rates. Less protein was degraded at high outflow rates and vice versa. At each fixed flow rate, high EPD was found for barley meal, followed by oat meal. The lowest EPD was found for fish meal.

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The influence of transportation time on the quality of broiler meat

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Mielnik, M. and Nils Kolstad 1991. The influence of transportation time on the quality of broiler meat. Norwegian Journal of Agricultural Sciences 5:245-251. ISSN 0801-5341.

The aim of the experiment was to investigate the effects of various transportation time on the technological characteristics of broiler carcasses and post-mortem(PM) changes in breast muscles. One hundred and fifty broiler chickens were randomly divided into five groups and transported for 0, 1, 2, 3 and 4 hours immediately before slaughter. They were deprived of food and water 12 hours before slaughter. The live weight losses as a result of starvation were higher for transported chickens than untransported. However, transportation time had no effect on these losses. Oven-ready yields were significantly reduced after 3 hours of transport. The biochemical parameters which characterize the early PM changes were not influenced by transportation time in breast meat. Likewise, roast loss, pH of breast meat and tenderness of thigh meat were not dependent on length of transportation time. Only shear values of breast meat and pH of thigh meat were affected by extended transportation time. Untransported broilers had the most tender breast meat as well as the lowest pH values in thigh meat.

Key words: Broiler, post-mortem changes, tenderness, transporation time, yield.

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Transportation of broiler chickens from farm to slaughter house should be considered as one of the reasons for pre-slaughter stress. During transport, the birds are subjected simultaneously to stresses such as fear, vibration and density. The order of a normal day is disturbed and social grouping suffers a breakdown. The birds are deprived of food and water, and also the opportunity to rest. Moreover, the chickens suddenly find themselves in completely new surroundings and subjected to external influences. The consequence of these circumstances is anxiety and excitement amongst the birds.

Results of previous reports indicate that extended transportation time leads to an increase in live shrinkage in chickens (Scholtyssek 1974, Ehinger 1977, Scholtyssek et al. 1977, Ehinger & Gschwindt 1978). Transportation is also claimed to have a negative effect on the meat and carcass quality of broilers

(Scholtyssek & Ehinger 1976, Ehinger 1977, Ristic & Schön 1977, Scholtyssek et al. 1977, Ehinger & Gschwindt 1978, Ehinger & Gschwindt 1979, Ehinger & Gschwindt 1981). Some chickens, and even the whole strain, show a relatively high susceptibility to stress (Ehinger & Gschwindt 1981). In view of the fact that Norway has a nationally bred strain of commercial broilers, it was considered valid to investigate certain characteristics of meat and carcass quality of broilers which had been subjected to different transportation time.

MATERIAL AND METHODS

One hundred and fifty broiler chickens reared in the experimental broiler house at the Institute were used in this study. They were fed the same diet and were reared in the same way. The broiler chickens were 40 days old and of mixed sex from one commercial strain. The birds were randomly divided into five treatment groups of 30 chickens immediately prior to the experiment.

The experiment was designed to determine the effects of transportation times of 0, 1, 2, 3 and 4 hours. There was a constant starvation time of 12 hours for all treatment groups in order to separate the effects of starvation and transportation time. Transportation time was thereby included in the starvation time.

The chickens were weighed, individually tagged and placed in transportation crates in the broiler house at the start of the starvation period while waiting for transportation. All the chickens were reweighed just before transportation. They were then loaded on to the lorry and transported for the relevant time, i.e. 1, 2, 3 or 4 hours, after which they were weighed a third time. The transportation loss of live weight (%) was calculated on the basis of weight before and after transportation.

The control group chickens (0 h) were killed immediately after the second weighing and processed in a laboratory plant under the following conditions: they were first stunned mechanically and then killed conventionally by an exterior neck cut. After bleeding for two minutes, the carcasses were scalded at 66°C for 40 seconds and machine plucked for ca one minute.

The pH in the breast muscles was recorded 15 minutes after slaughter. At the same time, about 10 g samples of breast muscles(Pectoralis Major) were taken and immediately frozen in liquid nitrogen for R value, glycogen and lactic acid analyses. The samples were stored at -70°C until used.

Each carcass was then eviscerated. Feet, head and ends of wings were cut off and the carcasses were reweighed. Oven-ready yields (%) based on the initial weight (prior to starvation) and also on the weight directly before slaughter were calculated.

Carcasses were chilled by submersion in slush-ice until the next day. The final pH was then measured in the breast muscle. The chilled carcasses were packed in plastic bags and stored in the freezer at -20°C until they were analysed. The carcasses were thawed at 4°C for 48 hours before analysis.

Assessment of roast loss

Each half of the 15 carcasses per treatment was packed in a baking bag and roasted in a convection oven at 175°C to an internal temperature of 90°C. Roast losses (%) were calculated on the basis of weight before and after heating.

Assessment of tenderness

The breast and thigh meat from the roasted halved carcasses were ground separately in a meat grinder (4 mm holes). Meat samples of 40 g were placed in a Kramer shear cell (6.5 x 6.5) and sheared on an Instron (TM-SM) at a crosshead speed of 100 mm/min. The shear values measured from the peak force were expressed as kg force per 1 g sample.

Measurements of pH

The pH of breast muscles was measured with a digital Altotest 2 pHMeter fitted with an Ingold combined glass electrode. The electrode was inserted in a freshly made incision 15 minutes and 24 hours post-mortem (PM). Moreover, the pH was recorded in breast and thigh meat homogenate after thawing. A slurry was made by homogenization of meat and water in a ratio of 1:1.

Biochemical analyses

Glycogen was determined according to the enzymatic methods of Dalrymple & Hamm (1973) using commercially available reagents from Boehringer, Mannheim GmBh.L actic acid was determined by the enzymatic method in accordance with the instructions enclosed in the Diagnostic Kits from Boehringer, Mannheim GmBh.The R value (ratio of inosine to adenine nucleotides) was determined in accordance with Honikel & Fischer's (1977) method.

All data were subjected to statistical analysis using the General Linear Model (GLM) and correlation procedure described by the SAS Institute Inc. (1985).

The Scheffe's multiple range test was applied to determine differences between means.

RESULTS AND DISCUSSION

The influence of transportation time on the shrinkage of live weight and oven-ready yield of experimental chickens is presented in Table 1.

The initial live weight ranged from 1242 g to 1581 g and averaged 1402 g. The variance analysis did not show any significant differences between treatment groups. The live weight losses during 12 hours of starvation were significantly influenced by transportation. Chickens which were slaughtered without being transported lost approximately 0.8% less of their live weight than transported chickens. However, transportation time had no effect on live weight losses. The significant differences in shrinkage of live weight between the untransported group and the transported groups starved for the same period of time probably could have been due to stress caused by loading, transportation and additional weighing.

The live weight losses considered only in the context of transportation time showed a close relationship ($R^2 = 0.74$). The transportation weight losses of experimental chickens increased significantly with an increase in transportation time. However, the weight losses expressed per

Table 1.The effect of transportation time on live weight losses and the oven-ready yield of chickens

Transport time h	Initial weight g	Live weight losses during 12 h starvation %	Live weight losses during transport %	Oven-ready yield based on: Initial weight %	Oven-ready yield based on: Preslaughter weight %
0	1395	6.80 b	0.00 d	55.41 a	59.45 a
1	1458	7.61 a	1.40 c	55.03 a	59.57 a
2	1362	7.63 a	2.22 b	55.12 a	59.67 a
3	1385	7.41 a	2.65 b	54.46 ab	58.82 ab
4	1355	7.85 a	3.69 a	53.61 b	58.18 b
F value	1.14^{NS}	5.02***	102.36***	5.12***	3.89**
R^2 value	0.04	0.12	0.74	0.12	0.10

Each value is the mean of 30 observations

a-b Means followed by different letters in each column are significantly different ($p < 0.05$)

NS: Not significant. ** and *** significance at the 0.01 and 0.001 levels respectively

hour showed a downward trend to 3 hours, after which there was an increase.

Live weight losses reported by other authors have shown considerable differences, depending on the experiment. Scholtyssek (1974) noted losses of 2.8%, 3.1% and 3.4% in chicken live weight in an experiment with 45, 90 and 135 minute transportation times respectively. In a second trial with transportation times of 2, 4 and 6 hours ,he found losses of 1.81%, 2.72% and 3.21% respectively. Scholtyssek et al. (1977) reported that the reduction in live weight amounted to 1.27%, 2.25% and 3.08% after 1.5, 3.0 and 4.5 hours, respectively. Results of experiments carried out by Ehinger (1977) on broilers transported after different starvation periods indicated that weight losses were significantly influenced by transportation time (2 hours - 1.59%, 4 hours - 2.45%) and they were reduced by a period of starvation before transportation. Ehinger & Gschwindt (1978) found that transportation weight losses were dependent on the season in the year. They obtained considerably higher values, viz. 2.45%, 3.90% and 4.57% after transportation times of 2, 4 and 6 hours in the winter compared with the data acquired in the summer (1.09%, 2.01% and 3.01%, respectively).

Oven-ready yields of experimental chickens based on both initial and preslaughter weights showed the same tendency (Table 1). There were no significant changes with less than 3 hours of transportation. After this, a yield reduction was observed. The lowest oven-ready yields were noted for chickens transported for 4 hours. Our results are contrary to the findings of Scholtyssek et al. (1977), who found that yield calculated on the basis of preslaughter weight was not affected by transportation time. In addition, Ehinger (1977) observed the significant yield increase also calculated on the basis of preslaughter weight after a 2 and 4 hour transportation time compared with untransported broilers.

The early PM changes in breast muscles of broilers with regard to the various transportation times are presented in Table 2. A comparison of the average values did not reveal any significant dependency on the duration of transport for the biochemical parameters. It seems that the lack of differences between treatment groups was due to the wide variation in the parameters examined. The initial pH values ranged from 5.7 to 6.98, while the final pH reached values between 5.68 and 6.22. Values for glycogen, lactic acid content and IMP/ATP ratio (R value) ranged between 7.85 and 64.48; 22.36 and 103.31 and 0.89 and

Table 2.The effect of transportation time on the biochemical changes in breast muscles of chickens

Transport time h	Initial pH 15	Final pH 24	R value (250/260 nm) g fresh muscle	Glycogen as µ Mol glucose/ g fresh muscle	Lactic acid µ Mol/
0	6.45	5.88	0.98	39.13	47.35
1	6.49	5.91	0.97	39.34	52.14
2	6.39	5.87	0.97	34.38	53.10
3	6.63	5.92	0.94	39.31	43.53
4	6.50	5.83	0.95	40.04	48.35
F value	0.86^{NS}	1.37^{NS}	0.64^{NS}	0.58^{NS}	0.47^{NS}
R^2 value	0.05	0.07	0.03	0.03	0.03

Each value is the mean of 15 observations
NS: no significant difference between means

Table 3. Correlation coefficients of the relationships between biochemical parameters and shear value of chicken breast muscles

	Glycogen	Lactic acid	pH 15	pH 24	Shear value
R value	-0.75***	0.83***	-0.71***	-0.18 NS	0.36**
Glycogen		-0.85***	0.76***	-0.02 NS	-0.24*
Lactic acid			-0.85***	-0.17 NS	0.38*
pH15				0.27*	-0.32**
pH24					-0.38***

NS: Not significant, *, ** and *** significance at the 0.05, 0.01 and 0.001 levels respectively

1.26, respectively. This great scattering of the individual data could be explained by differences in reaction to transport and other stress factors. Although the mean values of biochemical parameters indicated normal glycolysis of breast muscles, nevertheless birds with deviations were found. Among the 75 broilers, 16 birds with particularly accelerated glycolysis were found. However, this was not the case with slow glycolysis. The estimation was made in the first instance on the basis of $pH_{15} = 6.0$ and R value = 1.0. Lactic acid and glycogen content appeared very helpful.

As expected, a relatively close relation existed between the biochemical parameters measured in breast muscles 15 minutes after slaughter (Table 3). The highest coefficients of correlation calculated from all birds were ascertained for lactic acid content.

The influence of transportation time on the early PM changes in breast meat is as yet the subject of only a few research works. Partmann (1976) could not prove any effect of transportation time by examining indicators of post-slaughter changes such as pH, lactic acid, the labile energy-rich phosphate (P) and IMP content. Instead, Scholtyssek et al. (1977) found a decrease in pH after a 2 and 3 hour transportation time compared with 1 hour in the first experiment. However, the second experiment did not show any influence. Ehinger & Gschwindt (1981) reported a decrease in pH in both breast and thigh muscles 15 minutes after slaughter for broilers transported for 4 and 6 hours in relation to broilers transported for 2 hours. They could not find any differences for pH of both muscles measured 24 hours after slaughter.

The mean values of roast loss, pH in meat slurry and shear force measured in thawed carcasses are shown in Table 4. A variance analysis did not reveal any significant influence of transportation time on roast loss. Results obtained by other authors are divergent; some confirm our conclusions others contradict them. Scholtyssek & Ehinger (1976), working on thigh meat, did not find any influence of transportation time (2, 4 and 6 hours) on roast losses. Results published by Scholtyssek et al. (1977) showed no effect either. Ehinger (1977), in two factorial experiments with various starvation and transportation times, noted an increase in cooking loss after 2 hours of transportation compared with untransported broilers, with a decrease after 4 hours. The most significant differences were only in thigh meat whereas cooking losses of breast meat were at the same level in the three experimental groups. Ehinger & Gschwindt (1978), examining the influence of transportation time in winter and summer on broiler quality, did not find any differences between the various transportation times although roast losses recorded in summer were higher than those in winter. These same authors (Ehinger

Table 4. Effect of transportation time on roast loss, pH and erness of chicken meat measured after thawing

Transport time h	Roast loss %	Breast meat pH	Breast meat Shear value (kg/g)	Thigh meat pH	Thigh meat Shear value (kg/g)
0	23.43	5.84	2.07 c	6.49 c	1.46
1	25.23	5.86	2.39 ab	6.59 ab	1.36
2	24.63	5.81	2.38 abc	6.65 a	1.42
3	23.92	5.85	2.14 bc	6.61 ab	1.35
4	25.17	5.78	2.48 a	6.56 b	1.39
F value	1.97 NS	2.35 NS	2.87*	6.53***	1.17 NS
R2 value	0.10	0.12	0.14	0.27	0.06

Each value is the mean of 15 observations.
a-c: Means followed by different letters in each column are significantly different ($p < 0.05$). NS: Not significant, * and *** significance at the 0.05 and 0.001 levels respectively

& Gschwindt 1979) observed a significant decrease in roast losses in breast and thigh meat with prolonged transportation time. Subsequent work by Ehinger & Gschwindt (1981) showed no effects of transportation time (2, 4 and 6 hours).

Mean shear force values of experimental broilers presented in Table 4 indicated that transportation time affected only breast meat. The significant lowest value (tenderest meat) for untransported broilers was noted. The highest mean value was calculated for broilers transported for the longest time, i.e. 4 hours. There were no differences between the 1, 2 and 3 hour transportation times.

The shear force values were significantly correlated with biochemical parameters measured in breast muscles 15 minutes after slaughter (Table 3). However, higher values of correlation coefficients, -0.47 and -0.48 respectively, were found with regard to the relationship between the shear values of breast and thigh meat and their pH measured after thawing. Meat which had a lower pH value needed a higher shear force, which means less tenderness.

The pH of the breast meat from the thawed carcasses was not affected by transportation time (Table 4), just like initial pH measured 15 minutes PM and final pH recorded 24 hours PM. As far as the pH of thigh meat is concerned, slurry from the same carcasses was significantly influenced by transportation time. The lowest mean value was noted for untransported broilers while the highest mean value was found for broilers transported for 2 hours. The pH increased up to 2 hours and then decreased with prolonged transportation time. We are unable to compare our results with other findings as this kind of measuring does not exist. Results on tenderness obtained by other authors often vary greatly. For instance, Scholtyssek & Ehinger (1976) reported a negative effect of extended transportation time (4 and 6 hours versus 2 hours) on the shear values of thigh meat, mainly in summer. However, Scholtyssek et al. (1977) were unable to show any influence on shear value in experiments with a 1, 2 and 3 hour transportation time. Ehinger (1977) found that both breast and thigh meat from broilers transported for 2 hours were tougher than those transported for 4 hours. The tenderest meat was obtained from untransported broilers. Investigations carried out by Ehinger & Gschwindt (1978) in two different seasons of the year indicated that extended transportation time from 2 to 6 hours improved the tenderness of breast and

thigh meat in winter, whereas prolongation of transportation up to 6 hours in summer had a significantly negative effect on the tenderness of both meats. Results of their other experiments (Ehinger & Gschwindt 1979, 1981) showed significant dependency of shear value on the transportation time but only for breast meat. Transportation for 4 hours in the first case seemed to have the worst effect while in the second the tenderness of breast meat was best after this time.

Results obtained in this study would suggest the necessity of curtailing transportation times to 3 hours, since after this time both oven-ready yield of carcasses and tenderness of breast meat will suffer reduction.

ACKNOWLEDGEMENTS

The authors express their appreciation to Mrs Kari Wold for her capable technical assistance in obtaining the experimental data. Mrs Anne Utvaer is thanked for reviewing the English text.

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Results from beef crossbreeding in Norwegian cattle

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van Hulten, M.-C., G. Klemetsdal & T. Steine 1991. Results from beef crossbreeding in Norwegian cattle. Norwegian Journal of Agricultural Sciences 5: 253-259. ISSN 0801-5341

A comparison of purebred Norwegian Cattle (NRF) with Charolais x NRF, Hereford x NRF and Aberdeen Angus x NRF crosses was carried out for carcass weight, carcass value, fat and grade classifications. In relation to NRF, Charolais crosses have a 10% increase in age-adjusted carcass weight, similar fat classification, superior grading scores and a 12.8% higher carcass value. The average age-adjusted carcass weights for Hereford- and Aberdeen Angus crosses were 4.2% and 3.4% higher than those for NRF, while the corresponding results for the carcass values were 4.3% and 2.6% higher, respectively. Both the Hereford- and the Aberdeen Angus crosses had better grading scores but more fat than NRF. The Aberdeen Angus crosses were relatively most competitive with NRF when slaughtered at 13-15 months of age.

Key words: Breed differences, carcass composition, crossbreeding, economics, growth.

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In Norway Charolais semen has been available for crossbreeding in the dairy herds since 1965.

Gravir (1973, 1975) found carcass weight in 12-18 months old crossbred Charolais bulls to be 8-9% higher than that in purebred Norwegian Cattle (NRF) bulls at the same age. In addition, several detailed carcass classification results were in favour of the crossbreds at that time. Since then, crossbreeding with Aberdeen Angus and Herefords has also become more frequent in the NRF population. Consequently it is interesting to compare the performance of the different crossbreds in relation to NRF. In this study, carcass weight, fat- and grade classification results recorded directly on the slaughter line, as well as the carcass value, were analysed.

MATERIAL AND METHODS

The data in this study were collected from 37 slaughterhouses in the years 1987, 1988, 1989 and in the first four months of 1990. In this period 1211 re-

cords were available on crossbred bulls. Of these 297 were Hereford crosses (H), 795 Charolais crosses (Ch) and 119 Aberdeen Angus crosses (AA). To make a reliable comparison of these breeds, data from 4332 NRF bulls raised in the same herds as the crossbred bulls were added to the material.

The information available for each animal was: identification of herd and animal, date of birth, sire, dam, maternal grandsire, date of slaughter, carcass weight, grade and fat scores. Grade and fat scores were recorded subjectively on a scale from 1 to 5 for grade and 0 to 3 for fat. In this respect, a value of 5 for grade is assumed to reflect the best possible classification result, while for fat score the values show the percentage of fat in the carcass (0 = 0% fat, 1 = 1-5% fat, 2 = 6-10% fat, 3 = >10% fat). Carcass value was calculated from the carcass weight, fat and grade scores by using the actual value in NOK based on prices from the Norwegian Meat Marketing Board by 10. August 1990.

The material was divided into three data sets, each of which included herds with pure NRF and one of the actual crosses.

Exclusion of data because of small herd size and extreme age at slaughtering resulted in the three data sets including herds with at least 6 slaughtered animals, all between 13 and 22 months of age. The total numbers of herds and animals in the final data sets are given in Table 1.

Table 1. Number of animals and herds in the three comparisons

Comparison	1		2		3		Total
	HxNRF	NRF	ChxNRF	NRF	AAxNRF	NRF	
No. of animals	143	459	473	1425	65	231	2796
No. of herds	63		199		31		293

The comparisons were made by fitting the following linear model to the data:

$$Y_{ijkl} = \mu + A_i + B_{ij} + H_k + e_{ijkl}$$

where:

Y_{ijkl} = carcass weight, carcass value, fat and grade scores
μ = least squares mean
A_i = fixed effect of breed
B_{ij} = fixed effect of age within breed
H_k = fixed herd effect
e_{ijkl} = random error $\sim N(O, \sigma^2_e)$

The comparison of breeds is carried out by using weighted averages over the age interval 13-22 months. Estimates of least squares means for different age groups within breed give an indication of possible interaction between the age at slaughtering and breeds.

RESULTS

Table 2 gives the least squares means for the different crosses and the purebreds in the three comparisons.

Average carcass weights for Hereford- and Aberdeen Angus crosses were 4.2% and 3.4% higher than carcass weight for purebred NRF while Charolais crosses on average weighed 10% more than the purebreds.

Fat scores for Charolais crosses were low compared to those for the other beef crosses as their average was equal to that

Table 2. Least squares means with standard error for carcass weight, carcass value, fat and grade scores

Comparison		C.weight	C.value	Fat score	Grade score
1	H x NRF	269.08 ± 2.23	11161 ± 102	1.79 ± 0.05	3.95 ± 0.06
	NRF	258.05 ± 1.44	10692 ± 66	1.46 ± 0.06	3.52 ± 0.04
2	Ch x NRF	287.16 ± 1.50	12135 ± 67	1.39 ± 0.03	4.48 ± 0.04
	NRF	258.83 ± 0.84	10756 ± 37	1.39 ± 0.01	3.58 ± 0.02
3	AA x NRF	270.81 ± 3.31	11156 ± 149	2.04 ± 0.07	3.95 ± 0.08
	NRF	261.96 ± 1.85	10874 ± 84	1.44 ± 0.04	3.50 ± 0.05

of the purebreds. Aberdeen Angus crosses appeared to have the highest quantity of fat, while Hereford crosses in this respect were somewhere between the Charolais- and Aberdeen Angus crosses. The grading scores for Charolais crosses exceeded those for the purebred NRF and the other two beef crosses. On average Hereford- and Aberdeen Angus crosses had similar grade classifications.

The composite effect of carcass weight, fat and grade scores is reflected in the carcass value. In this respect the Charolais crosses were 12.8% superior to purebred NRF, clearly reflecting the increased value from both the higher grading scores and the higher carcass weight. Similarly, the value for the Hereford crosses was 4.3% higher than that for NRF while the value for the Aberdeen Angus crosses exceeded that of purebred NRF by 2.6%.

In Table 3, detailed information from the analysis of variance is presented. In this table the degrees of freedom, mean squares and degrees of significance are shown per trait and effect. It appears that all differences are significant at the 5% level, with the exception of the two comparisons between purebred NRF and Charolais crosses for fat scores and Aberdeen Angus crosses for carcass value.

The most important result with respect to growth is carcass weight, and results from the three comparisons over the age classes are shown in Figs 1, 2 and 3.

As expected, each of the beef crosses

Table 3. Degrees of freedom, estimated mean squares and levels of significance in the three comparisons

Comparison	Effect	Carcass weight DF	MS	P	Carcass value MS	P	Fat score MS	P	Grade score MS	P
1 H	Herd	62	7957.70	**	15334273	**	1.49	**	1.98	**
	Beef cross	1	7454.76	**	13443937	**	6.63	**	11.37	**
	Age	18	8312.93	**	16690245	**	0.64	**	2.61	**
2 Ch	Herd	198	6113.79	**	11861835	**	1.29	**	1.75	**
	Beef cross	1	161843.47	**	383326876	**	0.00	0	163.51	**
	Age	18	35352.93	**	70392274	**	1.96	**	5.15	**
3 AA	Herd	30	6105.09	**	12134519	**	1.29	**	1.26	**
	Beef cross	1	2789.27	*	2818543	0	13.07	**	7.11	**
	Age	8	3258.97	**	641203	**	0.49	**	0.61	*

Level of significance (P)
0: $P \geq 0.05$
*: $0.01 \leq P < 0.05$
**: $P \leq 0.01$

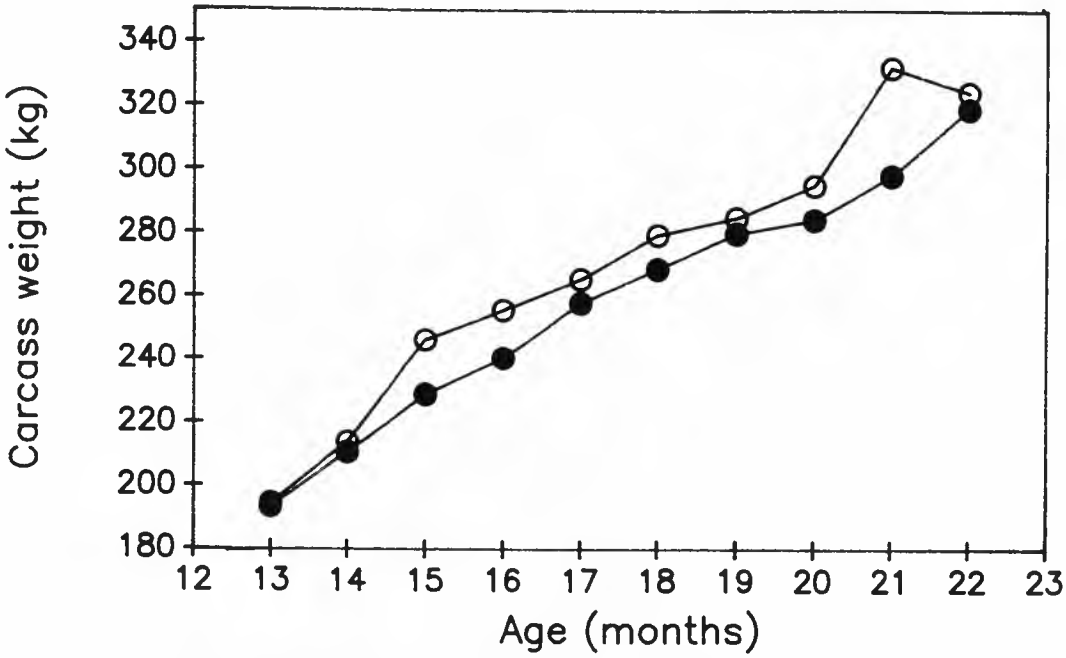

Fig.1. Least squares means of carcass weight in successive age classes (13-22 months); comparison 1.
o = Hereford crosses
● = NRF

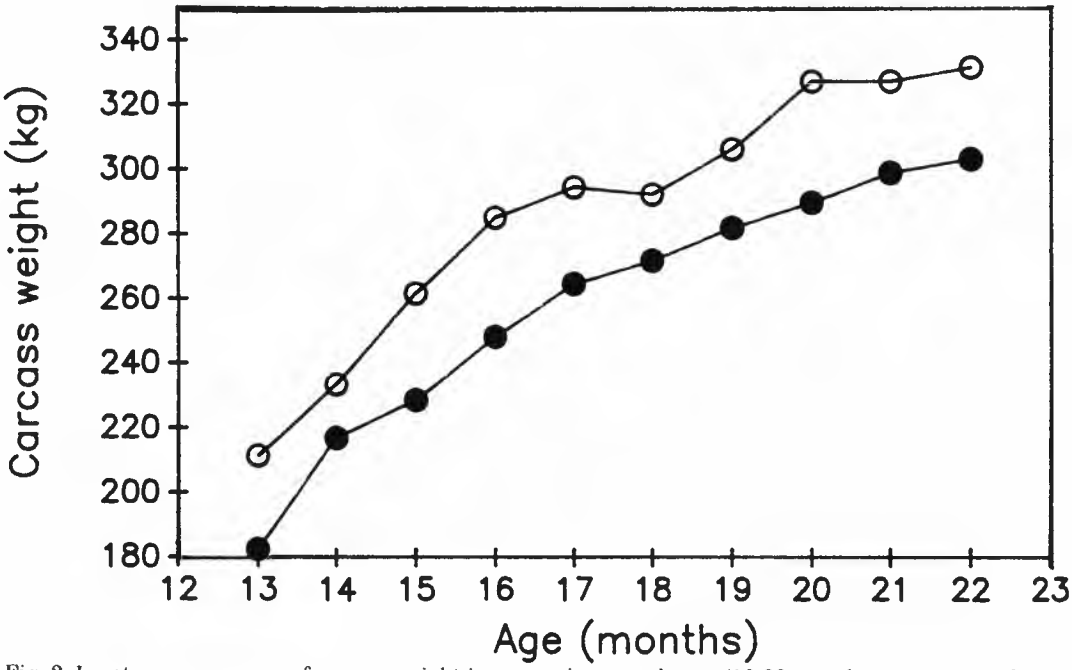

Fig. 2. Least squares means of carcass weight in successive age classes (13-22 months); comparison 2.
o = Charolais crosses
●= NRF

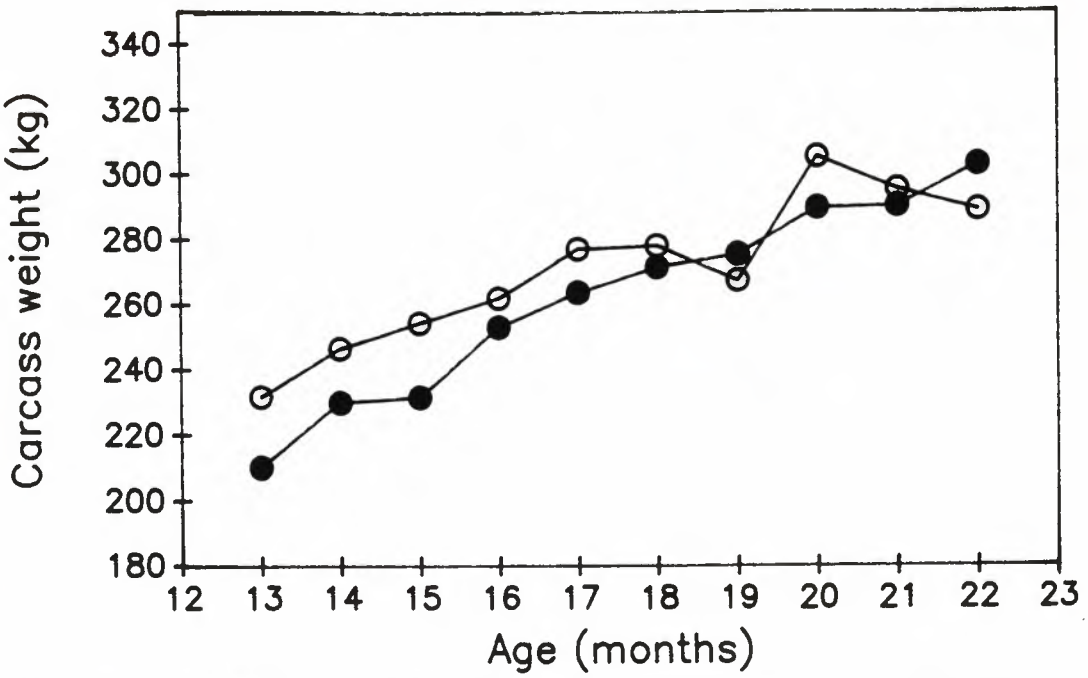

Fig. 3. Least squares means of carcass weight in successive age classes (13-22 months); comparison 3.
o = Aberdeen Angus crosses
● = NRF

gained more weight than the purebred NRF. The Charolais- and the Hereford crosses showed a consistently higher carcass weight than the purebreds over the entire age interval. The Aberdeen Angus crosses were very fast-growing in the beginning, but as a result of the early maturity of the Aberdeen Angus breed, the growth rate slowed down from about 17 months of age. Then the carcass weight of the purebreds was even higher than that of the Aberdeen Angus crosses. Because of early maturing the Aberdeen Angus crosses are expected to increase their fat scores at this age, thereby having lower scores for grading. This general tendency was also observed in this material. However, for Hereford- and Charolais crosses the relative superiority over purebred NRF for fat and grading scores did not change over the age classes.

A similar comparison over the age classes for the difference in carcass value between the three crossbreds and the purebred NRF is shown in Fig. 4. The figure clearly demonstrates the increased value from crossbreeding with Charolais in relation to crossbreeding with Hereford or Aberdeen Angus.

For Aberdeen Angus the carcass value compared with NRF was most valuable at low ages. At higher ages these crosses were unable to reach the value of the purebreds because of fat gain at an earlier age.

DISCUSSION

The results in this study are based on data collected under field conditions in Norway. Originally these data were collected for progeny testing for beef traits in the NRF population. As a by-product of this recording, slaughter data from crossbred bulls were also available, hence al-

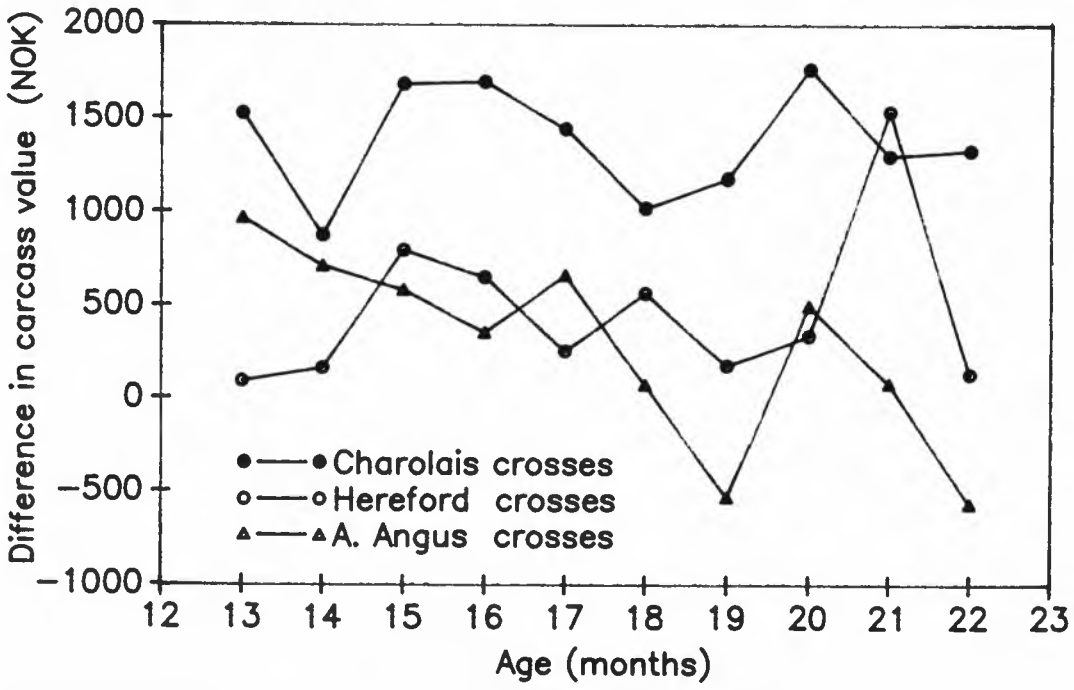

Fig. 4. Carcass value (in NOK) for beef crosses compared with NRF in successive age classes (13- 22 months). Carcass value for NRF = 0

lowing for a comparison of the different beef crosses with purebred NRF. However, the data have some obvious limitations. Generally, it is not possible to estimate additive and combining effects of the various breeds from this kind of data. This might be desirable, but would require a designed experiment.

The data were very limited in the highest age classes and therefore did not allow for a proper study of possible interaction effects between age and breeds. It can also be questioned whether it was reasonable to handle data from several years simultaneously and to allow for only one common herd effect, since it may have been more precise to split this effect into herd/year effects. This, however, would result in very small herd classes and consequently less accurate results. The data for fat and grading scores were subjectively measured and it is not clear whether the grading personnel would notice whether a carcass was purebred or crossbred. If so, the judging might have been biased and the comparison could be affected. Thus, further comparisons should be based on additional objective measurements of meat quality. In this study carcass weight and carcass value were measured objectively and the results for the Charolais crosses confirm the conclusions of Gravir (1973, 1975). Similarly the results indicate that crossbreeding of NRF with Aberdeen Angus is profitable when the animals are slaughtered at 13-15 months of age.

The extra gain in the crossbred animals requires an additional feed cost compared with pure NRF. To obtain the net gain from crossing with beef breeds the extra feed cost must be subtracted from the carcass value.

However, final decisions on which breeds are to be used in crossbreeding with dairy cattle should not be based only

on the increased value of surplus calves. Equally important are further studies on meat quality. Additional information about calving difficulties is also required.

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The efficiency of fluorescent lamps in young lettuce plant production

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Grimstad S.O. 1991. The efficiency of fluorescent lamps in young lettuce plant production. Norwegian Journal of Agricultural Sciences. 5:261-167. ISSN 0801-5341.

The relative efficiency of six different kinds of fluorescent lamps for growth and development of young *Lactuca sativa* L. plants was examined. The experiments were carried out in a greenhouse under winter light conditions (latitude 60°N), and in growing rooms without natural daylight. The irradiance level of all lamps in the experiments was 15 W m^{-2} (in the wavelength range 400-1000 nm) and plants were irradiated for 18 h day^{-1} over a period of three weeks. In greenhouses, as in growing rooms, growth in terms of fresh and dry weight as well as leaf number and chlorophyll content were higher for plants grown in light from Osram L/Fluora than those grown in light from the other lamps. Used only as a greenhouse supplemental light source, there were no differences in plant growth or development between Philips TLD/33 and Philips TLD/84. In growing rooms, however, Philips TLD/33 was more effective than the latter. As judged by fresh and dry weight Atlas Warm White was less effective than the former light sources in all cases, while Philips TLD/83 was the least effective light source in both greenhouse and growing rooms. Measurement of the spectral energy distribution as well as the recorded growth responses showed that the effects of Philips TLD/84 and Osram L/Lumilux were identical.

Key words: Fluorescent lamps; greenhouses; growing rooms; lettuce; light quality; propagation.

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In Norway fluorescent tubes have been the major artificial light source for plant production for many years (Kristoffersen 1965). In the last decade, however, high-pressure sodium lamps have been highly recommended. Fluorescent tubes are still used successfully in young plant production of greenhouse vegetables and vegetables for outdoor planting in the early spring. In spite of the development of several types of fluorescent tubes in the past three decades, cool- white and warm-white tubes (colours 33 and 29, respectively) are still mainly recommended for use in greenhouses as they were 20-25 years ago.

Growing rooms are widely used for year-round production of uniform seedlings for subsequent cultivation in greenhouses and open fields. So far, very little

Table 1. Relative energy distribution in percentage of total energy emission in different wavebands for the different types of fluorescent lamps

Wavelength (nm)	Fluorescent lamps				
	TLD 33	TLD 83	TLD 84	AWW	OFL
Blue 400 - 500	28.7	17.6	26.8	18.9	33.2
Green - yellow 510 - 610	42.9	31.9	33.4	42.2	10.9
Red 610 - 700	22.3	34.0	27.0	31.2	43.7
PAR* 400 - 700	93.9	83.5	87.2	92.3	87.8
Far-red 700 - 750	3.1	5.5	4.2	4.0	9.7
Infrared > 750	3.0	11.0	8.6	3.7	2.5

* PAR = Photosynthetically active radiation

work has been done on the evaluation of fluorescent tubes for growing rooms in commercial horticulture (Helson 1965; Biran & Kofranek 1976; Andersen 1986). In practice, the same types of tubes are recommended for both greenhouses and growing rooms.

Much research has been focused on the effect of the spectral energy distribution (light quality) of different light sources (Bickford & Dunn 1973; Bacher & Hallig 1975; Cathey & Campbell 1975; Grimstad 1982, 1987; Tibbitts et al. 1983). It is shown that at high latitudes with poor natural light conditions during the winter, light sources with a relative poor emission in the wavelength range 400-500 nm are less effective than light sources with a more balanced energy distribution (Grimstad 1981,1982). The present report investigates the following questions: (1) are the commonly recommended fluorescent tubes the most efficient light sources for raising young lettuce seedlings in greenhouses and growing rooms compared with other lamp types of fluorescent tubes, and (2), can the same tubes be recommended for both greenhouses and growing rooms?

MATERIALS AND METHODS

Plants of the lettuce (*Lactuca sativa* L.) cultivars Nordia and Ostinata were grown from seed in a greenhouse. After emergence, the seedlings were transplanted to 0.5 l plastic pots containing standard fertilized peat (Floralux). The seedlings, one in each pot, were then selected for uniformity and placed in separate greenhouse compartments and growing rooms where six different types of fluorescent lamps were installed.

Lamps of the following types were tested: Philips TLD58W/33 (TLD 33), Philips TLD58W/83 (TLD 83), Philips TLD58W/84 (TLD 84), Atlas 85W Warm White (AWW), Osram L 58W/21 and Osram L 58W/Fluora (OFL). The spectral characteristics of each lamp type in the wavelength range 400-1000 nm were determined with a UDT- 1100 A/B spectroradiometer (United Detector Technology, USA). The energy distributions were determined by integrating the area under the curves for the respective band widths (Table 1).

The irradiance was adjusted to 15 W m^{-2} (400-1000 nm) at plant level, as

Table 2. Corresponding values in lux and μmol m^{-2} s^{-1} for the different types of fluorescent lamps

Lamp types	Irradiance W m^{-2} (400-1000 nm)	lux	μmol m^{-2} s^{-1} (400-700 nm)
Philips TLD/33	15	6750	103
Philips TLD/83	15	5720	97
Philips TLD/84	15	6590	108
Atlas Warm White	15	5670	87
Osram L/Fluora	15	2820	105

measured with an UDT-80X radiometer (Deutch & Rasmussen 1974). Corresponding values in lux and μmol m^{-2} s^{-1} as measured with a Lambda Instrument LI-185B (LI-COR, USA) are presented in Table 2.

All plants were irradiated for 18 h day^{-1} (0600-2400 h). The air temperature was maintained at 18 ± 1°C in the greenhouse and 18 ± 0.5°C in the growing rooms. The relative humidity was maintained at 75 ± 5% and CO_2 concentration at 340 μl l^{-1}.

The irradiation treatments were commenced 10 days after seeding. Plants were watered with a complete nutrient solution containing the following elements (mg l^{-1}): N, 158; P, 32; K, 209; Ca, 103; Mg, 35; S, 32; Fe, 1.8; Mn, 0.8; Zn, 0.16; Cu; 0.11; B, 0.16; Mo, 0.03 - which gave an electrical conductivity of 1.8 mS cm^{-1}.

The study was repeated three times during the winter, with the lamp types moved between greenhouse compartments and between growing rooms in order to check compartment/room variability.

Each experimental period lasted for three weeks. The average natural photosynthetic photon flux density (PPFD) inside the greenhouse in the three experiments, was 3.1, 1.3, and 6.1 mol m^{-2} day^{-1} respectively (Data from the Department of Physics and Meterology, Ås). The natural PPFD inside the greenhouse was about 58% that of the outside.

The three experiments in these studies were used as replicates, each plot containing nine plants of each cultivar.

Growth parameters measured at the end of each experimental period included fresh and dry weight of the foliars, number of leaves ≥ 1 cm, leaf length and width. Chlorophyll content was determined on lamina tissue. Fresh tissue was ground and chlorophyll extracted with 80% acetone and concentration determined by measuring absorption at 645 and 663 nm (Ziegler & Egle 1965). Three samples were taken from each plot.

The Philips fluorescent tube TLD58W/33 was chosen as a reference, as this is the most commonly used tube in greenhouses and growing rooms. The data were subjected to an analysis of variance, and Duncan's multiple range test was used to determine the significant difference between treatment means at the $P \leq 0.05$ level.

RESULTS

The measurement of the spectral energy distribution as well as the recorded growth responses indicated that the effects of the fluorescent tubes Philips TLD 84 and Osram L 58W/21 were identical. Therefore, only the results for TLD 84 are mentioned.

No significant interaction could be found between cultivars and light treatment. The results are therefore presented as an average for the two cultivars.

Greenhouse

Light quality had a strong effect on growth and morphogenesis. The growth in terms of fresh weight was highest in

Table 3. Effects of different fluorescent lamps on growth and development of lettuce in greenhouse (means of two cultivars). Values within rows followed by different letters are significantly different at $P \leq 0.05$ level according to Duncan's multiple range test

Growth parameter	Fluorescent lamps				
	TLD 33	TLD 83	TLD 84	AWW	OFL
Plant f.w. (g)	56.7b	42.2d	59.1b	53.2c	94.1a
Plant d.w. (g)	2.7b	1.9d	2.8b	2.4c	4.2a
No. of leaves ≥ 1 cm	11.3b	9.8c	11.0b	10.7b	14.2a
Leaf length (cm)	7.8b	8.3a	8.1ab	8.2a	7.8b
Leaf width (cm)	4.4a	4.1b	4.4a	4.3ab	4.4a
Chlorophyll content a + b (mg dm^{-2})	2.0b	1.9c	2.0b	1.9c	2.2a
ratio a/b	3.2b	3.6a	3.4ab	3.3b	3.5a

light from OFL. (Table 3). Compared with TLD 33 as reference, TLD 83 and AWW showed limited plant growth. The trends for dry matter production were the same as for fresh weight: OFL > TLD 84 = TLD 33 > AWW > TLD 83.

Ranking the light source according to leaf production produced nearly the same order. The number of leaves was significantly lower under TLD 83 than under all the other light sources. Leaf production under the TLD 84 and AWW lamps was not significantly different from that under the reference lamp TLD 33. Leaf length under TLD 33 and OFL lamps was similar and significantly shorter than for any other treatment. No significant differences in leaf width were recorded between the light sources, except for TLD 83 with smaller leaves.

The highest chlorophyll content was found in plants exposed to OFL; these plants also became visibly more dark green than the other plants. Compared with those exposed to light from TLD 33, plants exposed to light from TLD 83 and AWW became paler and the chlorophyll content was lower. In this respect no significant differences were found between TLD 33 and TLD 84. Also the ratio between chlorophyll a and b was influenced by the light source. Highest chlorophyll a/b ratios were found in plants from TLD 83 and OFL.

Table 4. Effects of different fluorescent lamps on growth and development of lettuce in growing room (means of two cultivars) Values within rows followed by different letters are significantly different at $P \leq 0.05$ level according to Duncan's multiple range test

Growth	Fluorescent lamps				
	TLD 33	TLD 83	TLD 84	AWW	OFL
Plant f.w. (g)	50.1b	27.9e	43.1c	35.5d	94.0a
Plant d.w. (g)	2.5b	1.4e	2.2c	1.7d	4.0a
No. of leaves ≥ 1 cm	11.2b	8.8d	10.0c	10.0c	14.2a
Leaf length (cm)	7.7a	7.7a	7.6a	7.6a	7.8a
Leaf width (cm)	4.2a	3.7c	4.2a	4.0b	4.3a
Chlorophyll content a + b (mg dm^{-2})	1.6b	1.3c	1.4bc	1.3c	1.9a
ratio a/b	3.0b	3.1b	2.6c	2.8bc	3.4a

Growing room

With the exception of leaf length, the differences between the light sources were more pronounced in growing rooms than in the greenhouse (Table 4).

On the basis of the results for plant growth in terms of fresh and dry weight, the following ranking of light source efficiency could be made: OFL > TLD 33 > TLD 84 > AWW > TLD 83.

For all parameters recorded in the experiment, a significant interaction between light source and daylight was identified (Table 5). In light from OFL, plant growth and development was virtually unaffected by excluding daylight, except for a significant reduction in the chlorophyll content.

For the TLD 33 lamps, a moderate reduction in fresh and dry weight was found when daylight was excluded, while exclusion of daylight significantly reduced chlorophyll content and the chlorophyll a/b ratios.

Plants grown in light from TLD 83, TLD 84 and AWW showed the greatest response to the exclusion of daylight with significant fresh weight reductions. In treatments with these lamps, a reduction in number of leaves and leaf length and width could also be observed. The reduction in chlorophyll content was similar for the three lamps, but the reduction in the ratio of chlorophyll a/b was significantly greater with light from TLD 84 than from AWW and TLD 83.

DISCUSSION

The results demonstrate many of the problems that currently have to be faced in the selection and use of artificial light sources for plant growth.

In the experiment, the efficiency of the light sources was compared at identical irradiance (15 W m^{-2}) in the wavelength band 400-1000 nm. Plant growth and development in light from different lamp types were markedly different. This was clearly demonstrated by the OFL and TLD 83 lamps. In the greenhouse, fresh and dry weight in light from OFL was about double that in light from TLD 83. In the growing rooms this difference was even more striking.

The poor correlation between the use of terms such as illuminance (lux) and plant growth is also clearly demonstrated. On the basis of lux values (Table

Table 5. Effects of excluding daylight on growth and development of lettuce grown under different fluorescent lamps (means of two cultivars). Percentage reduction

Growth parameter	Fluorescent lamps				
	TLD 33	TLD 83	TLD 84	AWW	OFL
Plant f.w. (g)	11.6**	33.9***	27.0***	32.6***	0.1ns
Plant d.w. (g)	5.9*	26.9***	21.3***	28.8***	4.0ns
No. of leaves ≥ 1 cm	1.0ns	9.9*	9.0*	7.1*	0.0ns
Leaf length (cm)	1.2ns	6.7*	5.6*	7.3*	0.3ns
Leaf width (cm)	3.6ns	10.4**	5.5*	6.4*	1.6ns
Chlorophyll content a + b (mg dm^{-2})	22.6***	30.5***	27.4***	28.5***	15.0*
ratio a/b	6.8*	14.0**	24.1***	15.7**	3.4ns

Significance of interaction: (Light source x daylight):

Plant f.w.	***	Chlorophyll content a + b	***
Plant d.w.	***		
No. of leaves	**	ratio a/b	***
Leaf length	*		
Leaf width	**		

2) one would expect the lowest growth with OFL lamps. If the light sources are compared on the basis of PPFD, as is normally recommended, one would expect TLD 33, TLD 84 and OFL to be almost equal in efficiency and AWW to be considerably lower. As shown in Tables 3 and 4, this is not in accordance with the results of the experimentation.

Experiments such as those conducted by McCree (1972) using leaf sections and with individual narrow wavebands of the spectrum, indicate that in the short-term, photosynthetic response is directly related to the total incident quantum flux in the 400 -700 nm waveband, irrespective of the distribution of the flux within this region (Warrington et al. 1976). On this basis, the effects of any particular light source on photosynthesis will be determined by the total output of photosynthetic flux per watt of electric power consumed. However, in the long-term, the lamp type affects plant development, as well as photosynthesis (Warrington et al. 1976; Andersen 1986; Grimstad 1982, 1987). Thus the spectral energy distribution is indeed an important factor, and the efficiency of the light source to convert electrical power (input) into PI (photosynthetic irradiance), lux or PPFD alone is not a reliable criterion for selection of lamps for commercial plant illumination.

The most striking effects of light source were found on fresh and dry weight. The enhanced effect observed with the use of the OFL lamp can possibly be explained by the following: (1) the high energy emission in the red and far-red; (2) the higher leaf number per plant; and (3) the higher chlorophyll content in leaves. The higher photosynthetic rate of OFL could be attributed to the considerable energy emitted in the red and far-red as compared to a larger emission in the green and yellow for the other lamps (Bickford & Dunn 1973). It has also been shown (Emerson et al. 1957; Emerson & Rabinowitch 1960; Myers 1971) that radiation in wavelengths above 690 nm might be used more efficiently in photosynthesis when the plants also are receiving radiation in shorter wavebands (the Emerson effect). The lower fresh and dry weight obtained under AWW and TLD 83 might, therefore, be due to low emission in the blue region. The radiation in the blue region is probably not sufficient for a maximal utilization of the relative high emission in the red and far-red portions of the spectrum. For TLD 33 and TLD 84 the opposite might be true. For these lamps, the emission in the red and far-red might be too small for a maximal utilization of the blue radiation. In accordance with Helson (1965) this might also be the case for OFL. Experiments in growing rooms, conducted by Deutch & Rasmussen (1974), with white, cool-white and Gro-Lux (Sylvania) fluorescent lamps also show that supplementation of incandescent light increases plant growth. Rajan et al. (1971) found in their experiments that several species grew better under fluorescent lamps supplied with tungsten lamps, i.e., a high proportion of red and far-red light compared to fluorescent lamps alone.

Earlier experiments (Grimstad 1981, 1982) have shown that plant growth and development under light sources with a low emission in the blue range are more sensitive to variations in the amount of daylight than when using light sources with a high emission in the blue. This could explain the greater reduction in growth in light from TLD 83 and AWW when the daylight was excluded.

It can be assumed that the increase in fresh and dry weight of lettuce will follow sigmoid growth curves. The lack of significant differences in growth between plants grown under OFL in greenhouse and growing room may, therefore, be explained by the time of harvesting (Grimstad 1982). Lettuce plants develop a large number of leaves in a small area, and during the experiment as ground cover increases self-shading and shading between plants also increase. At some

stage the dark respiration rate of the plant will be equal to the CO_2 uptake and no further net dry weight accumulation will occur. (i.e. top of the sigmoid curve). It follows that sooner or later plants receiving different PPFD are all likely to reach similar dry weights.

The spectral energy distribution curve for the OFL lamps indicates that it closely follows that of chlorophyll synthesis. This is probably the primary reason why the chlorophyll content is higher in leaves under these lamps.

From a purely physiological point of view, OFL could be highly recommended for young lettuce plant production in both greenhouses and growing rooms. However, OFL, which is a lamp designed especially for plant growth, is more expensive than standard lamps such as TLD 33 and TLD 84. Technical and economic aspects will in the end be the decisive factors in the choice of lamps.

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Effects of Colt and F 12/1 rootstocks on growth, cropping and fruit quality of 'Ulster', 'Van' and 'Sam' sweet cherries

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Ystaas, J. & O. Frøynes. 1991. Effects of Colt and F 12/1 rootstocks on growth, cropping and fruit quality of 'Ulster', 'Van' and 'Sam' sweet cherries. Norwegian Journal of Agricultural Sciences 5:269-276. ISSN 0801-5341.

The field performance of three commercial important sweet cherry cultivars on Colt and F 12/1 rootstocks was assessed during the first eleven years in the orchard. All the cultivars grew as vigorously on Colt as on F 12/1 during the three year period before the trees started cropping. Later the trees on Colt grew moderately resulting in a tree size reduction of 64, 77 and 76 % in 'Ulster', 'Van' and 'Sam', respectively, when the size of 11-year-old trees on the two rootstocks was compared by canopy volume estimates. The trees on Colt were more precocious than those on F 12/1, which were less efficient than trees on Colt, as measured by the ratio of accumulated yield to the trunk cross-sectional area at the end of the experiment. Fruit characteristics such as fruit size, content of soluble solids and rain-induced cracking were unaffected by the two rootstocks tested. Trees on Colt are highly susceptible to drought. Unless irrigation can be provided, Colt is not recommended for shallow or dry soils. Trees on Colt are winter hardy in Norway.

Key words: Colt, F 12/1, fruit quality, rootstock, sweet cherry, vigour, yield efficiency.

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In order to make sweet cherry production more competitive a much smaller tree than that on which current production is based is needed. Among the different approaches to reducing tree size, the application of growth regulators (e.g. daminozide and paclobutrazol) or alternatively the development of dwarfing rootstocks has been of great importance. Reliance on growth retardants, however, must to-day be discarded because of the growing public concern about health hazards accompanying the use of growth regulators in fruit production. As a consequence, the development of dwarfing rootstocks for sweet cherries remains crucial for a future economically viable sweet cherry industry. The results of comprehensive breeding programmes carried out in England, Belgium and Germany have been seen recently when several promising, dwarfing cherry

rootstock selections were introduced (Webster 1981, Trefois 1985, Schmidt & Gruppe 1988).

Colt originated from a cross between *Prunus avium* L. and *Prunus pseudocerasus* Lindl. made at East Malling Research Station, England, in 1958, and was selected for release in 1971 (Webster 1981). Colt, representing the first alternative to mazzard (*P. avium*) or F 12/1 rootstocks, was met with great expectations. From the first field trial conducted by Pennell et al. (1983) it was evident that trees on Colt were precocious and tree size was reduced by one third to half the size of trees on F 12/1. It produced trees of good habit, firm anchorage and minimal suckering. Colt presented no incompatibility problems with all sweet cherry cultivars so far tested (Webster 1982). Trees grown on Colt were less susceptible to bacterial canker than those grown on F 12/1 (Garret 1986). However, Colt appeared to be highly susceptible to drought (Webster et al. 1977, Zahn 1980). The winter hardiness was questioned, as winter injury to rootstocks lined out in the nursery had been reported from Holland (van Oosten 1980).

Before a new rootstock is accepted and taken into common use by the growers, an evaluation of its performance under different soil and climatic conditions is needed. The introduction of Colt as a promising rootstock of moderate vigour initiated a field trial at Ullensvang Research Station, Western Norway, at latitude 60° N, where the performance of Colt and F 12/1 as rootstocks for three commercial important sweet cherry cultivars was assessed. Preliminary results of the trial have already been published (Ystaas 1990).

MATERIALS AND METHODS

Trees of the cultivars 'Ulster', 'Van' and 'Sam' on Colt and F 12/1 rootstocks were planted in spring 1980 as maidens without feathers. A randomized split-plot design with cultivars on main plots and the rootstocks on sub-plots with six replications was used. The trees were spaced 5.5 x 4 m. The soil was a loamy sand high in organic matter (6.7%). A 1-m-wide strip along the tree rows was covered with black plastic mulch during the first three years. Later the mulch was replaced by herbicide treatment. The alleyways between rows were kept under grass which was frequently mown. Records of trunk girth were taken annually after each growing season. Total yield including rain-induced cracked fruits, was recorded every year. Fruit size and fruit quality, as measured by the content of soluble solids and the percentage of cracked fruits, were determined on random samples of 100 fruits from each tree. Concentration of soluble solids was measured by an Atago digital refractometer from free-run fruit juice from 10 mature fruits of the 100-fruit sample. Tree volume estimates based on tree height and spread were made of 11-year-old trees at the end of the experiment using the equation for a paraboloid, $\frac{1}{2}\pi b^2 a$, where a is tree height from the lower scaffold branches and b is $\frac{1}{2}$ the average diameter of the canopy spread.

RESULTS

Tree size

The trees on both rootstocks made a good start. During the first four years trees on Colt had as vigorous a growth rate as trees on F 12/1. Later 'Ulster' and 'Van' on Colt gradually displayed some reduced growth as compared with trees on F 12/1 (Fig. 1). However, trees on 'Sam' showed quite a different pattern of growth vigour. During the whole experimental period (11 years) 'Sam' on Colt grew more vigorously than trees on F 12/1. As measured by the trunk cross-sectional area of 11-year-old trees 'Ulster', 'Van' and 'Sam' on Colt had 85, 84 and 102% the size of the trees on F 12/1, respect-

Table 1. Effects of rootstock on trunk cross-sectional area and canopy volume of 11-year-old trees planted in 1980

	Trunk cross-sectional area (cm^2)			Canopy volume (m^3)		
Rootstock	Ulster	Van	Sam	Ulster	Van	Sam
Colt	42.3	33.8	45.0	8.81	6.42	8.96
F 12/1	49.7	40.2	44.3	13.79	8.37	11.77
LSD 5%	NS	NS	NS	2.46	NS	NS

ively, (Table 1). An estimate of canopy volume (Table 1) indicates that the differences in tree size between trees on Colt and F 12/1 rootstocks are greater when this method is applied than when trunk girth measurements are used. The effect of rootstocks on tree size is not significant except for the canopy volume of 'Ulster'.

Winter hardiness

Even though Ullensvang is located at 60° North, the winter climate is relatively mild. During the experimental period the lowest winter temperatures were: January 1982 -14,4°C; January 1984 -11,3°C; December 1985 -11,6°C; January 1986 -14,5°C. During the experimental period (11 years) no winter injury occured to the trees on either rootstock.

Yield and fruit quality

As shown in Fig. 2 Colt induced early cropping. High yielding cultivars like 'Ulster' and 'Van' were more precocious on Colt than on F 12/1 during the first four cropping years, while trees of 'Sam', generally a low yielding cultivar in Norway, on Colt outyielded trees on F 12/1.

The differences in cumulative yields for the first eight cropping years were small and not significant between rootstocks (Table 2). However, 'Sam' on Colt had a 94% increase in accumulated yield over trees on F 12/1. If tree size is taken into consideration the yield efficiency in terms of kg yield/cm^2 trunk cross-sectional area of 'Ulster', 'Van' and 'Sam' is 25, 28 and 92% higher, respectively, in trees on Colt than those on F 12/1.

No significant difference in fruit weight and content of soluble solids is found between rootstocks (Table 3). Rain-induced cracking of fruits as presented in Table 4 shows that the cracking frequency is not influenced by the two rootstocks.

Nutrient and water supply

The results of chemical leaf analysis reported elsewhere (Ystaas 1990a) show

Table 2. Effects of cherry rootstocks on cumulative yield (1983-90) and cumulative yield efficiency of three cultivars

	Cumulative yield, kg/tree			Yield efficiency kg/cm^2		
Rootstock	Ulster	Van	Sam	Ulster	Van	Sam
Colt	72.1	85.7	36.8	0.50	0.92	0.23
F 12/1	78.6	95.1	19.0	0.40	0.72	0.12
LSD 5%	NS	NS	7.1	NS	0.20	0.08

Table 3. Mean fruit weight and concentrations of soluble solids of three cultivars as affected by cherry rootstock, means of eight cropping years (1983-90)

	Fruit weight, g			Soluble solids, percent		
Rootstock	Ulster	Van	Sam	Ulster	Van	Sam
Colt	7.8	7.7	8.4	18.5	18.7	17.0
F 12/1	7.9	8.1	8.1	18.0	19.2	16.4
LSD 5%	NS	NS	NS	NS	NS	NS

Table 4. Effect of rootstock on rain-induced cracking of three cultivars, means of six years

	Cracked fruits, percent		
Rootstock	Ulster	Van	Sam
Colt	23	33	17
F 12/1	20	33	12
LSD 5%	NS	NS	NS

that the leaf content of nitrogen and potassium was significantly lower from trees on Colt than trees on F 12/1, while the leaf calcium and magnesium content was significantly higher from trees on Colt than trees on F 12/1. During dry periods trees on Colt showed signs of water stress, while trees on F 12/1 did not. Trees on Colt had stunted growth on a few plots with shallow soils.

DISCUSSION

Trees on Colt are characterized by vigorous growth in the nursery and during the initial period (3-4 years) in the orchard. During this period trees on Colt grew as vigorously as trees on F 12/1 or mazzard rootstocks. These results are in accordance with reports by Pennell et al. (1983), Webster (1989), Zahn (1989) and Callesen (1991). Trees of the cultivars 'Ulster' and 'Van' subsequently grew more slowly. At the end of the experiment 11-year-old trees were 84 and 85% the size of trees on F 12/1, respectively, while 'Sam' on Colt was of same size as trees on the control rootstock. These findings indicate that cultivars may react differently on Colt and that tree size reduction is smaller than reported by Pennell et al. (1983) and Webster (1981). When tree size is estimated by canopy volume 11-year-old trees of 'Ulster', 'Van' and 'Sam' on Colt are 64, 77 and 76% the size of trees on F 12/1, respectively. As pointed out by Pennell et al. (1983) the tapering of the scion trunk of trees on Colt may account for an overestimation of tree size when girth measurement is used for estimating tree size. It is generally accepted that measurement of trunk girth gives an accurate estimate of relative size when comparing trees of the same scion/rootstock combination. When trees grafted on different rootstocks are compared the estimated differences may be much less accurate (Pennell et al. 1983).

McVittie (1984) maintains that Colt is not as winter hardy as *Prunus avium* rootstocks because of its *Prunus pseudocerasus* parentage. This is confirmed in laboratory tests for winter hardiness where Colt is rated as less hardy than F 12/1 and mazzard rootstocks (Strauch & Gruppe 1985, Howell & Perry 1990). In England winter injury to Colt lined out for budding has been experienced once in 10 years (McVittie 1984), while worked trees have not been damaged. In Denmark Callesen (1991) found no winter injury to young sweet cherry trees

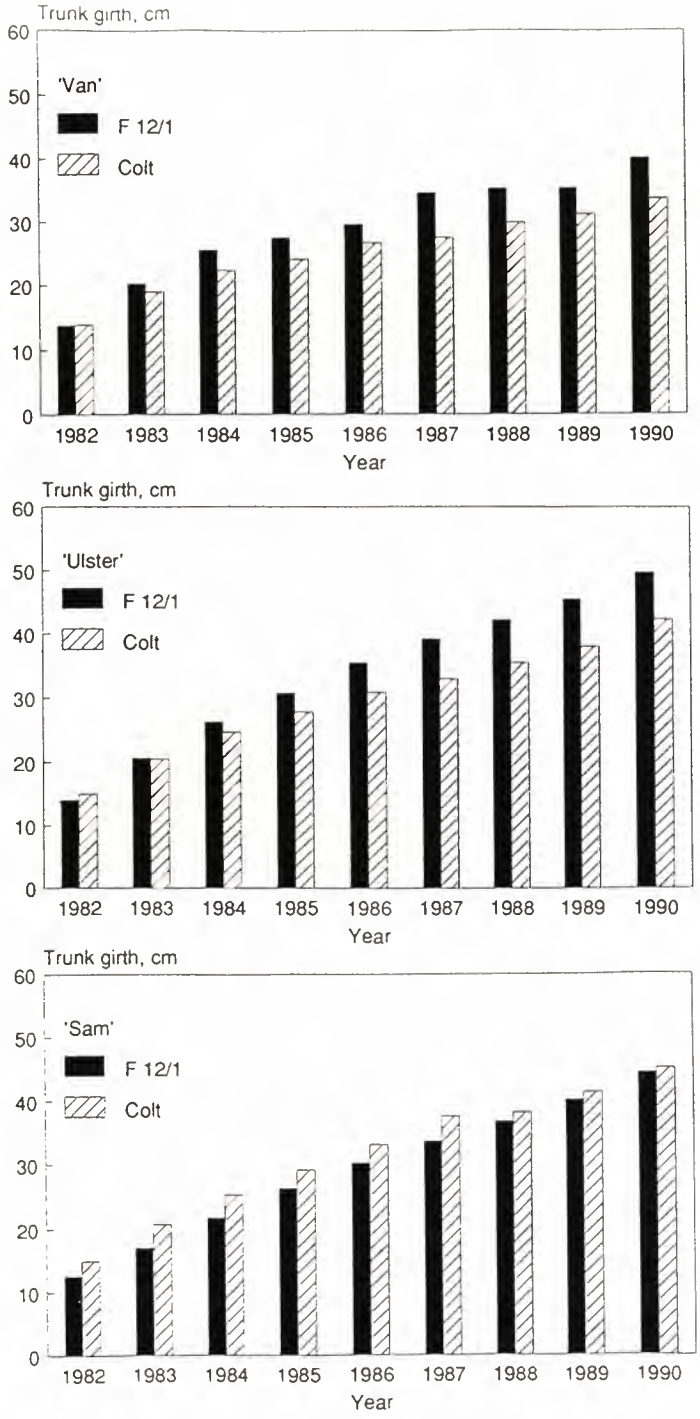

Fig. 1. Effect of rootstock on trunk girth of 'Van', 'Ulster' and 'Sam' sweet cherries planted in 1980 over nine years

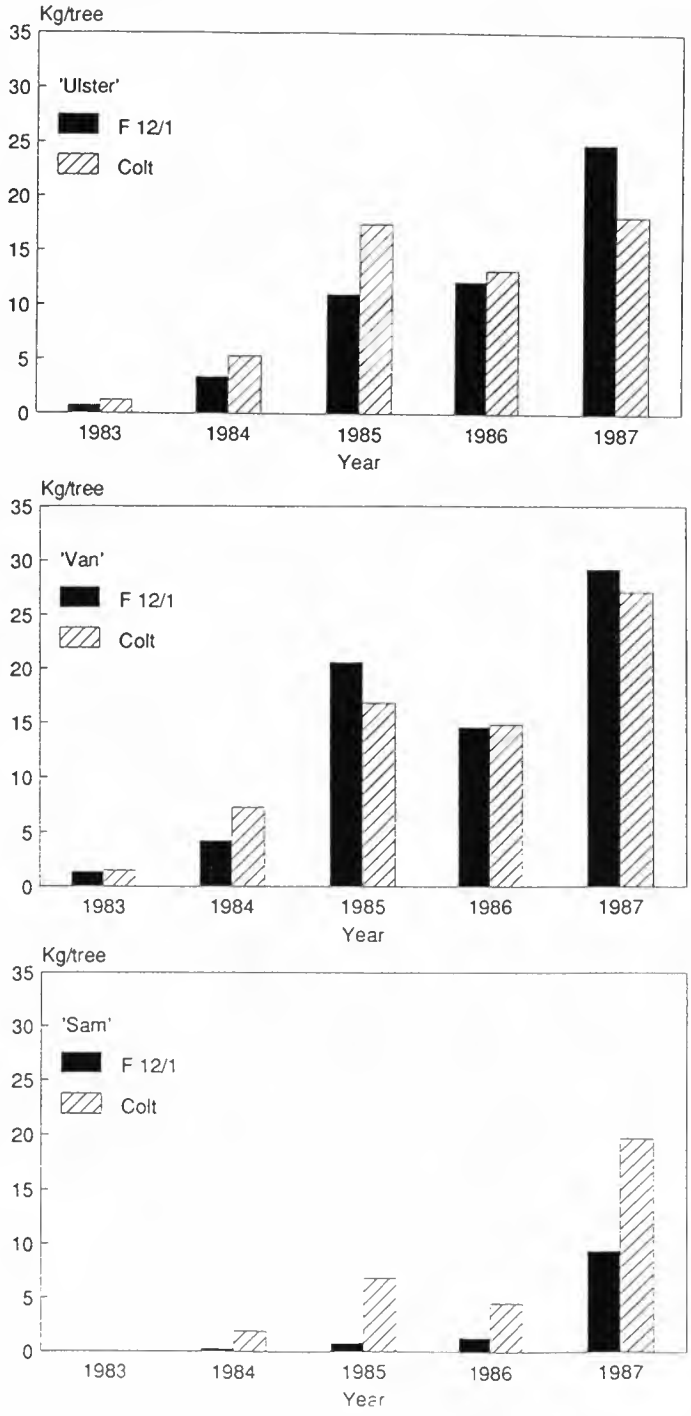

Fig. 2. Effects of rootstock on yield and precosity of three cultivars planted in 1980

on Colt at temperatures down to -19 to -24°C. This is in accordance with the results obtained in this experiment where the winter temperature of -14,5°C did not cause any winter injury. Serious losses because of frost damage, however, have been reported from Germany when winter temperatures as low as -22 to -30°C were experienced (Koch 1988, Vogel 1990).

The findings that Colt induces precocity and produces trees of higher yield efficiency compared with trees on F 12/1 and mazzard rootstocks are confirmed by the results obtained by Pennell et al. (1983), Zahn (1989), Callesen (1991) and Miller et al. (1990).

Apparently the root system of Colt is not well adapted to shallow or sandy soils where dry periods can seriously restrict the supply of water and nutrients. Vegetative growth is hence impaired and the trees are likely to become stunted. If irrigation cannot be provided, Colt cannot be recommended for shallow or dry soils (Claverie et al. 1985).

Attractive large fruits are an important component of sweet cherry fruit quality. Under favourable growing conditions fruit size is not negatively affected by Colt as demonstrated in this experiment and confirmed by the work of Zahn (1989). Colt is not drought-tolerant and trees under water stress are likely to produce significantly smaller fruits than trees on F 12/1 (Miller et al. 1990). The eating quality is strongly influenced by the content of soluble solids which in the present study is well above an acceptable quality threshold value of 14,2% as defined for sweet cherries by Vangdal (1980) and is not negatively affected by either rootstocks. This is in accordance with the report by Miller et al. (1990). Rain-induced fruit cracking is a serious problem in sweet cherry production and the suggestion made by Callesen (1991) that smaller and more open trees on Colt rootstocks may produce cherries that are less susceptible to cracking is not confirmed in this experiment.

SUMMARY

Trees on Colt are more precocious and efficient in production than trees on F 12/1. They are healthy and not susceptible to bacterial canker. The vigorous growth of trees on Colt experienced during the first few years following planting contributes toward creating a canopy and leaf area conducive to early high yields. The dwarfing effect of Colt is small and rootstocks more dwarfing are required for the full benefit of high density planting systems for sweet cherries. Trees on Colt are winter hardy in Norway. An undesirable characteristic of Colt is poor drought tolerance. Unless irrigation can be provided, Colt cannot be recommended for sandy soils.

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Evaluation of ten blackcurrant cultivars

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Heiberg, N. and F. Måge 1991. Evaluation of ten blackcurrant cultivars. Norwegian Journal of Agricultural Sciences 5: 277-282. ISSN 0801-5341.

An experiment was carried out in which ten blackcurrant cultivars were tested for vegetative and generative characters. It was found that the cultivars Ben Nevis and Ben Lomond had the highest yields, but both cultivars were susceptible to mildew. Hedda and P8/13/11 had the highest yields among the mildew-resistant cultivars. P8/13/11 had a very erect growth habit, but weak, narrow-angled branches, while Hedda had a spreading growth habit.

Key words: Blackcurrant, cultivars, disease resistance, growth habit, yield.

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Commercial production of blackcurrants in Norway covers 300 hectares. In addition the blackcurrant is an important fruit in home gardens.

Many of the cultivar requirements are similar for both commercial and home garden production, e.g. yield, disease resistance, erect growth habit, and adaption to climatic conditions. For hand harvesting, long racemes with large berries are preferred. For commercial production, fruit weight and raceme length are of less importance, because the berries are harvested by machine or the «beating method», a combined manual and mechanical harvesting method for currants developed in Norway (Nes 1986).

The cultivar Ben Nevis was recommended to growers after promising results in a cultivar trial (Thorsrud 1982), and is now the main cultivar for commercial production in Norway. In the past five years Ben Nevis constituted 41% of the certified stock plants sold in Norway. More recent cultivar evaluations have confirmed the high yield capacity of Ben Nevis (Groven 1983, Meland 1985, Gwozdecki 1988), and both Ben Nevis and Ben Lomond seem to have adapted well to the Norwegian climate (Heiberg 1986b). The cultivars Hedda and Øjebyn are recommended for home gardens as both are hardy and mildew-resistant.

The present study was conducted in order to investigate a number of cultivars and selections with regard to their generative and vegetative characters, and resistance to the most prevalent diseases.

MATERIALS AND METHODS

The experiment, which included ten blackcurrant cultivars, was carried out at the Department of Horticulture, Agri-

Table 1. Mean air temperature and precipitation, April-August at Blindern, Oslo

	1983	1984	1985	1986	1987	1988	Normal
Mean temperature, °C.	12.9	13.0	11.8	11.9	11.3	13.0	12.7
Precipitation, mm	245	367	469	303	305	500	339

cultural University of Norway (latitude 59°40'), with roughly the same climate as Oslo (Table 1) which is situated 25 km to the north. The cultivars were Ben Lomond, Ben More, Ben Nevis, Blackdown, Hedda, Malling Jet, Silvergieter, Øjebyn, and the sib-selections P8/13/11 (ND 12/26 x Westra) and P8/13/13 (Ben Tron) from the Scottish Crop Research Institute, UK.

The experiment was established in spring 1983 on heavy soil with good water capacity, and was situated at the bottom of a slope. The spacing was 4 m between rows, 2 m between the plants within the plot, and 2.5 m between plots. Planting was carried out as a randomized block design, with four replicates and three plants in each plot.

Most of the characters were recorded over a four or five-year period, with the exception of leaf fall and internode length which were recorded over two years while number of fruits per raceme, fruit drop and weight of prunings were recorded over three years.

Each year, the field was treated with 500 kg of calcium nitrate (15.5% N) per hectare. Irrigation was provided when required. Weeds were controlled with soil herbicides (simazine or terbutylazine) in recommended concentrations (3000 ml per hectare) every year.

Endosulfan was applied once in the flowering period to protect against blackcurrant leaf midge (*Dasineura tetinsi*). Against mildew (*Sphaerotheca mors-uvae*) and leafspot (*Pseudopeziza ribis*), fungicides were applied 2-7 times during the growing season, never later than two weeks before harvest.

Date of full bloom was set when 90% of the flowers in each cluster were open. The evaluation was carried out in two replicates, on five clusters of each bush and three times every week throughout the flowering period.

Winter damage occurred in 1985 and 1987, and the number of dead branches was recorded in late May. Diseases were recorded on an 0-5 scale (5 = severely attacked) approximately one month after harvest.

Mildew symptoms were observed

Table 2. Yield in tonnes per hectare of ten blackcurrant cultivars over five years

	1984	1985	1986	1987	1988	Mean
Ben Lomond	1.50	8.55	7.03	10.63	5.11	6.56
Ben More	1.07	6.15	4.83	5.29	5.23	4.51
Ben Nevis	2.22	9.79	8.59	11.29	5.29	7.44
Blackdown	2.03	6.65	6.53	6.79	3.95	5.19
Hedda	1.84	5.83	6.02	8.33	1.75	4.75
Malling Jet	0.95	4.70	2.27	3.47	3.90	3.06
Silvergieter	0.52	3.75	2.92	3.15	0.65	2.20
Øjebyn	1.32	5.95	5.22	6.90	1.74	4.23
P8/13/11	1.38	8.00	5.97	7.04	2.25	4.93
P8/13/13	1.60	5.34	5.04	5.93	0.45	3.67
Average	1.44	6.47	5.44	6.88	3.03	4.65
LSD						1.56

Table 3. Generative characters of ten blackcurrant cultivars

	Number of flowers per raceme	Number of fruits per raceme	Percent fruit-set	Weight in grams of 100 fruits	Weight in grams of 100 racemes
Ben Lomond	7.2	5.0	34	149	734
Ben More	9.3	7.0	23	126	806
Ben Nevis	8.3	6.0	32	142	847
Blackdown	9.5	7.9	19	109	822
Hedda	8.6	6.5	29	136	832
Malling Jet	14.2	11.4	26	69	733
Silvergieter	9.7	7.7	26	119	884
Øjebyn	8.7	7.7	15	107	779
P8/13/11	10.0	8.4	19	127	964
P8/13/13	9.8	8.1	20	121	894
Average	9.5	7.6	24	121	830
LSD	1.1	1.4	8	15	132

over four years, while the plants displayed leafspot and white pine blister rust symptoms (*Cronartium ribicola*) only in two years (1984 and 1988).

RESULTS

The yield, presented as tonnes per ha in Table 2, was on average 1.4 t the year after planting, between 5 and 7 t in the next three years, and only 3 t in 1988. Ben Nevis had the highest yield in all years, with an average of 7.4 t. Second was Ben Lomond with 6.6 t. Both cultivars had the highest yield in 1987, with more than 10 t per ha. Silvergieter had the lowest yield of all the cultivars.

The interaction between cultivars and years was statistically significant. In 1988 most of the cultivars failed except for Ben More and Malling Jet which both had relatively high yields in that year. P8/13/13 yielded only 0.4 t in 1988.

The mean value over five years shows that the number of flowers per raceme varied from 7.2 for Ben Lomond to 14.2 for Malling Jet (Table 3). The lowest number of flowers per raceme was found in 1987 (8.7), and the highest in 1985 (11.2).

Malling Jet had the highest number of fruits per raceme, and Ben Lomond the lowest. For fruit weight the ranking was the opposite, and the two cultivars consequently had equivalent weights of racemes. Øjebyn had the lowest fruit drop at 15%, while Ben Lomond and Ben Nevis had the highest at 34% and 32% respectively. P8/13/11 had the highest weight per raceme.

Full bloom occurred in late May (Table 4). The variation in date of full bloom was small. On average for all cultivars date of full bloom varied by one day between years. None of the cultivars had a variation of more than four days between years. The earliest flowering cultivars in all years were Hedda and Øjebyn, and the latest was Silvergieter. Silvergieter needed the shortest developing time and was the earliest ripening cultivar. Malling Jet needed a long period of development, and was harvested about 20 days later than Silvergieter.

The vegetative growth of Ben Nevis, Blackdown and Malling Jet was characterized by many long, new shoots from the base and short internode length (Table 5). Blackdown had the largest bushes. Hedda, P8/13/13, Øjebyn and P8/13/11, on the other hand, all had fewer new shoots and long internodes. The

Table 4. Phenological data of ten blackcurrant cultivars

	Date of full flower	Date of ripening	Number of days for development	Scores for leaf fall 0 = early 5 = late
Ben Lomond	May 26	Aug. 4	70	1.4
Ben More	May 30	Aug. 7	70	3.2
Ben Nevis	May 25	Aug. 3	71	0.8
Blackdown	May 30	Aug. 5	66	2.0
Hedda	May 23	Aug. 1	68	0.0
Malling Jet	May 30	Aug. 21	81	3.0
Silvergieter	June 1	July 31	60	3.0
Øjebyn	May 24	Aug. 1	68	0.0
P8/13/11	May 27	Aug. 2	68	2.6
P8/13/13	May 27	Aug. 1	65	2.3
Average	May 27	Aug. 5	69	1.8
LSD	2 days	3 days	3	0.4

shoots of Hedda and Øjebyn were short, while P8/13/11 had long shoots. P8/13/13 and P8/13/11 both had an erect growth habit, while all the other cultivars except Ben More were more or less spreading.

The branches of P8/13/13 and P8/13/11 were narrow-angled and weak, leading to some breakage every year. In 1985 and 1987 the branches of many of the cultivars died. Most likely this was caused by winter damage. Silvergieter lost most branches, with an average of 7.3 per bush for the two years, while P8/13/13, P8/13/11, Malling Jet, Ben More and Blackdown, in consecutive order, lost from 6.5 to 1.3 branches per bush. None of the branches of Ben Lomond, Ben Nevis, Øjebyn or Hedda died. The last four cultivars had the earliest leaf fall, while Ben More, Mal-

Table 5. Vegetative characters of ten blackcurrant cultivars

	New shoots from the base no	Length of the three longest shoots cm	Internode length mm	Weight of prunings kg	Bush height cm	Bush diameter cm	Ratio Height/ diameter
Ben Lomond	16	87	29	1.0	111	171	0.72
Ben More	14	86	29	0.8	110	165	0.80
Ben Nevis	18	94	24	1.2	118	181	0.73
Blackdown	21	98	26	1.4	122	188	0.69
Hedda	11	78	36	0.9	108	165	0.71
Malling Jet	16	95	25	1.3	112	185	0.64
Silvergieter	15	91	33	1.0	114	174	0.71
Øjebyn	14	80	36	1.1	106	166	0.69
P8/13/11	13	96	42	0.8	126	162	0.96
P8/13/13	11	85	33	0.6	122	151	0.97
Average	15	89	31	1.0	115	171	0.76
LSD	3	7	3	0.3	4	8	0.07

ling Jet and Silvergieter had the latest (Table 4).

Silvergieter was most affected by mildew, while no mildew symptoms were observed for Ben More, Hedda, Øjebyn and P8/13/11, P8/13/13, (Table 6). Ben More and Silvergieter were both highly affected by leafspot. The cultivars most susceptible to white pine blister rust were Ben More, Blackdown and Øjebyn. None of the cultivars were completely free from leafspot or blister rust.

Table 6. Scores (0-5) for visible symptoms of mildew (*Sphaerotheca mors-uvae*), leafspot (*Pseudopeziza ribis*) and white pine blister rust (*Cronartium ribicola*). 0 = free from symptoms, 5 = severely attacked

	Mildew	Leafspot	Blister rust
Ben Lomond	2.1	0.9	1.2
Ben More	0.0	1.5	2.6
Ben Nevis	1.9	0.6	0.6
Blackdown	2.0	0.9	2.3
Hedda	0.0	0.5	0.6
Silvergieter	2.9	1.4	1.3
Øjebyn	0.0	0.5	2.1
P8/13/11	0.0	0.6	1.3
P8/13/13	0.0	0.4	0.9
Average	0.9	0.9	1.3
LSD	0.6	0.7	0.7

DISCUSSION

The highest yielding cultivars tested, Ben Nevis, Ben Lomond and Blackdown, all need spraying against mildew. They should therefore not be recommended for home gardens. Ben Nevis and Ben Lomond have been used in commercial production in many countries for some years, and are both well suited to machine harvesting. The growth habit of Blackdown is vigorous and spreading and this cultivar should not be recommended for either commercial or home garden purposes. Ben Nevis and Ben Lomond have many rather weak shoots, giving them a spreading growth habit, and since the problem worsens with increasing nitrogen fertilizing, care should be taken with nitrogen supply.

The mildew-resistant cultivars were all low yielding. There is, however, a need for mildew-resistant cultivars, both for home gardens and for those growers who want to reduce the spraying programmes. P8/13/11 had the highest yield of the mildew-resistant cultivars, and with its heavy racemes this cultivar seems suitable for hand picking. The erect growth habit is a positive character, for both machine harvesting and home garden, but the weak and narrow branch angles might cause some problems. The late leaf fall and high number of dead branches in 1987 indicate poor climatic adaption. P8/13/13 is known as Ben Tron in Norway. This selection proved better than P8/13/11 in an unpublished clone trial at Kise Research Station planted in 1979 (Nes 1990). These two sib-selections are very similar in both vegetative and generative characters, but the present results indicate that P8/13/11 is a slightly better choice. The juice quality is good in both selections (Skrede et al. 1984).

Both Hedda and Øjebyn are well adapted to Norwegian climatic conditions, and are still actual cultivars, even though the juice quality of Øjebyn is rather poor (Blom & Skrede 1984, Heiberg 1986a), and Hedda has a low content of vitamin C (Haffner & Heiberg 1986). Hedda seems to be a better choice than Øjebyn, with a slightly higher yield and better growth habit, and higher resistance to blister rust. Both cultivars have a spreading growth habit, and should be grown with less nitrogen supply than the more erect cultivars.

SUMMARY

Ten blackcurrant cultivars were evaluated for vegetative and generative characters. Most characters were recorded over a period of four or five years.

Ben Nevis and Ben Lomond had the highest yields averaging at 7.4 and 6.6 t per ha respectively. Silvergieter had the lowest yield of all the cultivars.

Silvergieter was most affected by mildew, while no mildew symptoms were observed for Ben More, Hedda, Øjebyn and the sib-selections from the Scottish Crop Research Institute, P8/13/11 and P8/13/13. P8/13/11 and Hedda had the highest yields among the mildew-resistant cultivars with 4.9 and 4.8 t per ha respectively. P8/13/11 had an erect growth habit, but weak, narrow-angled branches, while Hedda had a spreading growth habit.

None of the cultivars were completely free from leafspot or white pine blister rust.

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Time of planting, fertilization, plant spacing and transplanting of sugar beet

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Lunnan, T., A. Skutlaberg & H.C. Svads 1991. Time of planting, fertilization, plant spacing and transplanting of sugar beet. Norwegian Journal of Agricultural Sciences 5: 283-288 ISSN 0801-5341

In 1979-83 a factorial experiment with 'Monohill' sugar beet was carried out at Ås, Norway, in which the mean sugar yield of sown beet was 4.92 t ha^{-1}. Transplanting increased the sugar yield by 2.70 t ha^{-1} and the sucrose content by 0.8%-units. A three week delay in planting resulted in a decrease in sugar yield of 0.54 t ha^{-1}. Increasing the amounts of fertilizer from 80 to 240 kg N ha^{-1} brought about a higher leaf yield and lower sugar content, but not a significantly higher sugar yield. Increased plant spacing within the row from 20 to 30 cm had only a small and negative effect on sugar yield and lowered the sugar content only at the earlier planting time.

Key words: Fertilization, plant spacing, planting time, sugar beet, transplanting, yield.

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Norway is one of the few countries in Europe without a national production of sugar. Sweden, Denmark and Finland produce 30-60% of the national demand from locally grown sugar beet (*Beta vulgaris* L.). Norwegian sugar production has been discussed from time to time, the main arguments being increased self-suffiency in food and the crop rotation effects of sugar beet as a break crop for cereal growers. The interest in this issue was especially high around 1980, and hence experiments with sugar beet were initiated at the Dept. of Crop Science. Some of these experiments are published by Skutlaberg (1981).

The short, cool growing season and the abundant rainfall in the autumn create the main problems for the cultivation of sugar beet in Norway. One way to prolong the season is to raise seedlings in a greenhouse and transplant them to the field. Transplants can better utilize the growing conditions during the early part of the growing season, and cultivation culminating in a high, stable yield is more assured. In Norway, the transplanting of forage root crops like rutabaga (*Brassica napus* L. ssp. rapifera Metzg. Sinsk.) and forage beet (*Beta vulgaris* L.) has increased during recent years. The results from the present experiment can partly be transferred to cultivation of forage beet, because of its close relationship with sugar beet.

MATERIALS AND METHODS

The beet variety used in the experiment was 'Monohill' from Hilleshög AB, Sweden. In 1979, the soil at the experimental field was characterized as a silt loam high in organic matter (20%), while in 1980-83 the soils constituted silt loams or silty clay loams with an organic matter content of around 6-7%.

A factorial (splitsplit-plot) design with three replications was applied at two planting times, as early as possible in the spring and then three weeks later, on the main plots; three fertilization rates, 80, 160 and 240 kg N ha^{-1}, on the medium sized plots, and combinations of plant spacing, 20 and 30 cm within the row, and sowing vs. transplanting on subplots.

The early planting in most years was carried out in the first half of May, except in 1983 when planting was delayed because of rainfall. The harvesting took place in the first half of October (Table 1).

A compound fertilizer (NPK 14-6-16) was applied, thus phosphorus and potassium were increased at the same rate as nitrogen. The spacing between rows was, for technical reasons, increased from 50 cm in 1979 to 60 cm in 1980 and to 65 cm in 1981-83. The number of plants per hectare was thus higher in the first two years (Table 3).

Table 1. Planting and harvesting dates

	Planting		
	Early	Late	Harvest
1979	May 11	May 31	Oct 17
1980	May 6	May 27	Oct 15
1981	May 12	Jun 1	Oct 8
1982	Apr 29	May 19	Oct 1
1983	May 25	Jun 7	Sep 28

Table 3. Plant density, 1000 plants ha^{-1}. Theoretically (Th), and observed plant density after sowing (S) and transplanting (Tr). Averages of planting times, fertilization levels and plant spacings

Year	Th	S	Tr
1979	83.3	60.3	82.3
1980	69.4	59.1	73.0
1981	64.1	54.1	68.7
1982	64.1	31.2	57.3
1983	64.1	63.5	61.7

Transplants were raised in a heated greenhouse in Jiffy pots filled with compost. They had four to six leaves at the time of transplanting. In 1979 and 1980 the transplanting was done by hand, and in the subsequent years by mechanical transplanter. Weeds were controlled with herbicides and also mechanically. In 1979 the field was harvested by hand, in 1980-83 a Thyregod root lifter was used after the leaf yield was recorded. The middle two of four rows per plot were harvested to avoid border effects.

Analyses

Samples of about 20 roots per plot were analysed for dry matter (DM) and sucrose

Table 2. Temperature and precipitation in the May-September period at Ås 1979-83

	Average temperature, °C						Precipitation, mm					
Year	M	J	J	A	S	M-S	M	J	J	A	S	M-S
1979	8.0	15.3	15.2	13.7	10.7	12.6	88	46	55	85	54	328
1980	11.7	15.7	16.2	14.8	11.7	14.0	60	136	47	75	75	393
1981	11.6	12.6	15.7	14.6	12.1	13.3	41	103	121	9	70	343
1982	9.6	13.9	17.6	15.8	11.9	13.9	94	48	49	96	93	380
1983	10.1	13.8	17.8	16.1	11.4	13.9	114	41	31	24	165	375
1931-1960 normal	10.2	14.4	16.8	15.6	10.9	13.6	49	70	79	96	86	380

content, and for soil contamination. The DM content of leaves was also assessed. The sucrose content was determined at the Chemical Analytical Laboratory, Agricultural University of Norway using the modified titerimetric (iodometric) Hagedorn-Jensen method. In 1981 an unreasonably low sugar content was found in some of the samples, probably because of fermentation. Therefore the sugar content (%) this year was calculated to 0.875 x root DM content - 4.383, which was the average linear regression between sucrose and root DM content for the other years of the experiment.

A factorial analysis of variance was applied, where the effects were tested against their interactions with years.

Weather

In 1979-83 precipitation and temperature during the growing season were close to the 1931-60 normal (Table 2). There was no severe early summer drought in these years, but in 1981-83 the July-August rainfall was lower than normal. In 1983 heavy rain in May caused delayed planting, and a drought the following summer reduced plant growth considerably.

RESULTS

Plant density

Very few of the transplanted plants died during the growing season. Sown plots had a lower number of plants than expected, except in 1983. In 1982 in particular, the plant density on sown plots was sparse because of poor germination (Table 3). Sown plots had an average of 72.7% and 85.2% of the theoretical plant number when thinned to 20 and 30 cm spacing within rows, respectively. Planting time and fertilization had only a small effect on the plant density.

Yield

Transplanting resulted in a higher yield than sowing in all years ($P<0.001$). On average transplanted plants yielded 55% more sugar than sown plants (Table 4).

A three-week delay in planting slightly decreased the average sugar yield from 6.54 to 6.00 t ha^{-1} ($P<0.10$). In 1982 the reduction was 1.27 t ha^{-1}, while in 1983 delayed planting increased the yield by 0.30 t. In three out of five years the yield decline was larger on sown than on transplanted plots (Table 5). Late sowing gave the higher yield in 1983.

On average increased fertilization

Table 5. Sugar yield decline (kg ha^{-1}) per day with delayed planting for sown (S) and transplanted (Tr) plants

Year	S	Tr
1979	11	39
1980	59	1
1981	44	13
1982	79	48
1983	65	19

Table 4. Yield (t ha^{-1}) of clean beet, sugar, and of dry matter (DM) in roots + 70 % of leaves after sowing (S) and transplanting (Tr). Averages of planting times, fertilization rates and plant spacings

	Beet yield		Sugar yield		DM yield	
Year	S	Tr	S	Tr	S	Tr
1979	29.4	49.5	4.56	8.07	9.57	15.24
1980	43.4	58.6	7.22	9.72	12.19	16.49
1981	37.1	50.9	5.33	7.87	10.00	14.05
1982	32.5	49.7	4.22	6.75	8.61	13.26
1983	23.8	38.2	3.28	5.67	6.04	9.63
Average	33.2	49.4	4.92	7.62	9.28	13.73

gave a slightly, though statistically non significant, higher sugar yield ($P>0.10$), with 5.97, 6.34 and 6.50 t ha^{-1} at 80, 160 and 240 kg N ha^{-1}, respectively. In 1979 there was no response at all to fertilization, and a negative response was recorded in 1982.

Increasing the spacing between the plants from 20 to 30 cm reduced sugar yield from 6.37 to 6.17 t ha^{-1} ($P>0.10$). There was no significant interaction between the experimental factors on sugar yield.

Transplanted beet gave a very high DM yield with a maximum of 16.5 t DM ha^{-1} in 1980 (Table 4). On average transplants yielded 4.45 t DM ha^{-1} more than sown plants. The root DM yield followed the same pattern as sugar yield. An increased level of fertilization increased both leaf and root DM yield (t ha^{-1}):

	Fertilization, kg N ha^{-1}			
	80	160	240	P value
Leaves, t DM ha^{-1}	2.59	3.26	3.70	<0.01
Roots, t DM ha^{-1}	8.79	9.44	9.61	<0.10

Sugar content

The average sugar content of roots varied between 13.3% in 1983 and 16.6 % in 1980. Except in 1983, delayed planting reduced the sugar content (Table 6). On average transplanting increased the sugar content by 0.8%-units ($P<0.05$). However, in 1980 sown and transplanted roots showed the same sugar content.

Table 6. Sugar content (%) of beet after early and late planting and with two planting methods. Estimated values in 1981

	Planting time		Planting method	
Year	Early	Late	Sowing	Transpl.
1979	16.1	15.9	15.6	16.3
1980	16.7	16.5	16.6	16.6
1981	15.5	14.3	14.4	15.5
1982	13.4	13.1	12.9	13.6
1983	14.2	14.4	13.7	14.8
Average	15.2	14.8	14.6	15.4

Increased fertilization rates resulted in a reduction in the average sugar content from 15.3% at 80 kg N ha^{-1} to 14.9% and 14.8% at 160 and 240 kg N ha^{-1}, respectively ($P<0.01$). Increased plant spacing lowered the sugar content (%) at the early, but not at the late planting time ($P<0.01$):

Plant	Planting time	
Spacing	Early	Late
20 cm	15.5	14.9
30 cm	14.7	14.9

Dry matter content

The average DM content of roots varied from 21.0% in 1983 to 24.0% in 1980. The DM content of leaves varied from 11.1% in 1979 to 13.6% in 1981. Increased fertilization rates reduced leaf as well as root DM content:

	kg N ha^{-1}			
	80	160	240	P value
Leaf DM content, %	13.2	12.7	12.5	<0.01
Root DM content, %	22.5	22.2	22.0	<0.01

On average transplanting gave an 0.9%-units higher root DM content, and an 0.4%-units higher leaf DM content, than sowing ($P<0.05$).

Soil contamination

The mean percentage of soil adherence was 21.3, 32.0, 22.0, 22.0 and 15.9% of the gross root weight in the years 1979-83, respectively. Early-planted beet had an average of 2.0%-units less soil than late-planted beet. This difference was most pronounced in 1980 at 5.0%-units, while there was no difference in 1983. Transplanted roots had a more spherical shape and a more proliferous root system compared with the conal roots of sown plants.

DISCUSSION

The average yield of sugar from sown beet was 4.92 t ha^{-1}. The lowest yield was recorded in 1983 at only 3.28 t ha^{-1} (Table

Table 7. Yield (t sugar ha^{-1}) and sugar content (%) in Norwegian experiments with sugar beet

Region, years	No. of exp.	Sugar yield	Sugar content	Reference
Agder 1905-16	18	3.27	16.7	Krosby 1918
Austlandet 1905-16	18	4.06	18.0	Krosby 1918
Jæren 1914-23	212	2.86	15.9	Hønningstad 1923
Hedmark 1928-32	65	3.71	17.9	Glærum 1933
Vestfold 1937-41	81	5.64	17.5	Vik 1944
Vestfold 1942	24	3.59	16.2	Vik 1944
Jæren 1958-60	10	5.95	15.8	Bjerga 1962
Austlandet 1958-60	11	4.04	16.0	Bjerga 1962
Sør-Austl. 1979-83	36	5.72	15.4	Not publ.

4); the result of a wet spring and late sowing followed by summer drought. In 1980, when the growing season was warm with an evenly distributed rainfall, the yield was very high at 7.22 t ha^{-1}.

It is remarkable that the yield of sugar in Vestfold 1938-41 and Jæren 1958-60 was higher than that in the present experiments (Table 7). The weather conditions for sugar beet were very favourable during these earlier experiments. The high sugar content measured in these experiments might be due to different varieties or to changes in the methods for analysis of sugar content.

Transplanted plants show a more rapid development of leaf area and thus can make better use of the early summer sunshine for photosynthesis and growth. Nevertheless, transplanting of sugar beet has not become a commonly used technique in Europe. In Japan the method is in general use (Masuda 1986). In Finland during the late sixties attempts were made to introduce transplanting, but without success. The growers found the plant propagation and transplanting too laborious. In practice, transplanting also was carried out later than the normal sowing time, leading to fewer yield advantages. Instead, the easier technique of drilling to final stand was preferred by the farmers (Brummer 1975).

Other means of speeding up seed germination and seedling growth have been tried. In Finland, Brummer (1961) mixed sand into silty clay soil, which gave a higher soil temperature and increased yield. A cover of sand or ashes on the snow to accelerate melting, thereby increasing the soil temperature, also gave good results. In Germany, Bürcky (1988) found that a transparent 0.02 mm polyethylene plastic cover gave a 2-3°C higher soil temperature and higher yield of early-sown sugar beet. After late sowing the effect of cover was rather negative because of injury caused by pests and diseases. In Norway, a cover of thin fibre cloth (polypropylene fibres) gave a 2.0 t ha^{-1} higher root DM yield in forage beet (Lunnan 1987).

The average increase in sugar yield of 2.70 t ha^{-1} by transplanting (Table 4), is of the same magnitude as that found in Germany (Bürcky 1988) and Belgium (Martens et al. 1974), but greater than that achieved in Finland (Brummer 1961, 1975). The advantage of transplanting was as its best in 1979, when the coolest growing season occurred. Transplanting also led to a higher sugar content (Table 6), which might have been due to more physiologically mature plants. In 1980, a warm year with evenly distributed rainfall, sown beet also reached a high maturity level with the same sugar content as transplants.

The more spherical root shape with more root branches is a serious disadvantage of transplants, which makes it more difficult to clean the roots and contributes towards increased losses during processing. In Japan, this pro-

blem is solved by making use of deep paper pots, which give a better root shape (Masuda 1986).

In Finnish trials (Brummer 1961, 1975) transplanting also caused more bolting. In the present experiments bolting caused no problems.

Early planting advances leaf and root development, which improves interception of light and the basis for further growth. On the other hand, sugar beet demands high requirements of seedbed and soil structure. Very early sowing in cold soil can cause poor emergence and bolting. Thus, in 1983 the later planting time gave the higher sugar content and yield. This must have been due to poor soil structure after heavy rain before the early planting time. In the other years early planting led to higher yield, higher sugar content and less soil contamination than late planting. Transplanted plants had a lower response to planting time than sown ones (Table 5).

Increased fertilization led to a higher DM yield, but had no statistically significant effect on sugar yield. This is in partial agreement with Augustinussen (1980), who found negative effects on sugar yield and quality by increasing the amounts of nitrogen from 75 to 150 kg ha^{-1}. In Swedish experiments the average optimum rate was found to be 112 kg N ha^{-1}, with variation from 33 to 183 kg (Frostgård 1989). The optimum rate varies according to crop rotation, climate and soil properties.

A dense and uniform plant stand produces the highest yield and the best quality sugar beet. Increased spacing from 20 cm to 30 cm between plants in the row reduced sugar yield only slightly. The sugar content was higher at 20 cm spacing at the earlier, but not at the later planting time. We have no good interpretation for this result. When transplanting, it would be profitable to increase the plant spacing within rows to more than 30 cm because of the lower plant propagation and transplanting costs.

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The effect of air temperature on the growth of foliage plants

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Mortensen, L.M. 1991. The effect of air temperature on the growth of foliage plants. Norwegian Journal of Agricultural Sciences 5: 289-294. ISSN 0801-5341.

Fifteen different foliage species were grown at temperature levels ranging from 15 to 33°C. The mean temperatures required for maximum dry weight production varied from species to species. These can be divided into three groups: Low-temperature plants with optimal temperature at <21°C (*Begonia rex-cultorum*, *Nematanthus radicans*, and *Saxifraga stolonifera*); intermediate-temperature plants with optimal temperature at 21-24°C (*Fatsia japonica*, *Peperomia caperata* and *Peperomia obstusifolia*); and high-temperature plants with optimal temperature at 24-27°C (*Aglaonema commutatum*, *Chlorophytum comosum*, *Codiaeum variegatum*, *Draceana fragans*, *Monstera deliciosa*, *Philodendron scandens*, *Rademachera sinica*, *Spathiphyllum wallisii* and *Syngonium podophyllum*). The optimal temperature for *S. podophyllum* and *R. sinica* was probably higher than 27°C, but this could not be ascertained since 27°C was the highest temperature applied to these species. Temperatures above 30°C often caused leaf injury and some species died off.

Key words: Foliage plants, temperature.

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The optimal control of air temperature is important in obtaining efficient greenhouse production of plants. While a great deal is known about optimal temperature regimes for growth of flowering crops, much less is known about foliage plants. Obviously, there are great differences in the optimal temperatures of species within this plant group (Sandved 1974, 1975, 1976; Mortensen & Larsen 1989). In most experiments, however, temperatures above 24°C have not been considered, and so the optimal temperature for growth often may not have been reached. Energy consumption in modern, well-insulated greenhouses is much less than it used to be, and high temperatures are therefore of greater interest today than they were some years ago. Furthermore, growing plants at high temperatures is also a question of the optimal use of solar radiation. In order to obtain more information regarding optimal temperatures for foliage plants several species have been included in this study.

MATERIALS AND METHODS

Three experiments were carried out using a total of 15 foliage species. The first experiment, including *Rademachera*

sinica Hemsl. and *Syngonium podophyllum* (Schott), and lasting 9 and 11 weeks, respectively, started on 1. April 1987. The second experiment, which started on 26. April 1988, and lasted 9 weeks, included *Begonia rex-cultorum* L.H. Bailey, *Codiaeum variegatum* (L.) A. Juss and *Nematanthus radicans* (Klotzsch. et Hanst. ex Hanst.). The third experiment included *Aglaonema commutatum* Schott, *Chlorophytum comosum* (Thung.), *Dracaena fragrans* (L.) Ker. Gawl., *Fatsia japonica* (Thunb.) Decne. et Planch., *Monstera deliciosa* Liebm., *Peperomia caperata* Yunker, *Peperomia obstusifolia* (L.) A. Dietr., *Saxifraga stolonifera* Meerb., *Philodendron scandens* K. Koch et Sello, and *Spathiphyllum wallisii* Regel. This experiment started on 30. March 1989 and lasted for 10 weeks, exept for the species *M. deliciosa*, *P. obstusifolia*, and *S. wallisii*, lasted for 12, 11 and 13 weeks respectively. Young plants of all species were placed in pots ranging from 8 to 13 cm depending on plant size. The substrate was standard fertilized peat (Floralux), and a complete nutrient solution was given two or three times a week. The plants were placed in daylight phytotrone compartments at different temperatures. Nine plants of each species were placed at each temperature level. From May in each year the plants were shaded because of the high solar radiation. The average light condition in all experiments at plant level was about 10 $molm^{-2}day^{-1}$, calculated on the basis of data from the Department of Physics and Meteorology at Ås. The relative humidity was 70-80% at all temperatures. CO_2 enrichment was not applied in the experiments.

At termination of the experiments, plant fresh and dry weight, plant height, number of leaves, and leaf colour and injuries were recorded. All data were subjected to an analysis of variance with single plants as replicates, and Duncan's multiple range test was used to determine significant differences between treatment means.

RESULTS

Maximal dry weight production was obtained at different temperature levels for the different species (Tables 1-3). Temperatures below 21°C substantially decreased the dry weight of *R. sinica* and *S. podophyllum*, and growth almost stopped at 15°C (Table 1). The growth of these species increased up to 27°C, which was the highest temperature included for these plants. Number of leaves as well as plant height also increased, parallel to the dry weight.

The dry weight of *B. rex-cultorum* de-

Table 1. The effect of temperature on growth of two foliage plants in Experiment 1. The initial values at the start of the experiment are given. Values followed by different letters are significantly different at $P < 0.05$ level according to Duncan's multiple range test

		Temperature (°C)				
	Initial	15	18	21	24	27
R. sinica						
Dry weight (g)	0.9	6.15c	11.44c	29.63b	37.50a	43.13a
Dry weight (%)	17.8	29.4b	31.0a	27.1c	28.1bc	28.2bc
No. of leaves	-	16.0c	17.0c	19.1b	20.6b	22.6a
Plant height (cm)	7.8	10.3e	19.0d	39.0c	53.3b	66.3a
S. podophyllum						
Dry weight (g)	0.4	0.84d	2.92c	10.7b	13.1b	18.1a
Dry weight (%)	8.7	12.9a	13.9a	11.8a	10.6a	9.8a
No.of leaves	-	12.2d	23.0c	47.9b	50.1b	69.6a
Plant height (cm)	7.5	9.2d	14.8c	33.0b	44.3b	76.3a

Table 2. The effect of temperature on growth of foliage plants in experiment 2. See Table 1 text

	Initial	Temperature (°C) 18	21	24	27	30	33
B. rex-cultorum							
Dry weight (g)	0.6		3.66a	2.91b	1.53c	Dead	Dead
Dry weight (%)	6.8		7.4b	7.4b	8.9a	-	-
No. of leaves	11.0		26.3a	20.0a	12.0b	-	-
Plant diameter (cm)	9.0		18.1a	15.4b	11.2c	-	-
C. variegatum							
Dry weight (g)	2.4		7.58ab	9.29a	10.51a	8.86a	5.77b
Dry weight (%)	14.4		16.8a	15.2a	14.6a	14.7a	15.1a
No. of leaves	8		14.1a	15.1a	14.9a	16.4a	13.9a
Plant height (cm)	-		11.6cd	13.4bc	14.1b	16.7a	10.0d
N. radicans							
Dry weight (g)	4.5		14.27a	14.42a	14.30a	7.91b	Dead
Dry weight (%)	6.6		8.6a	8.0b	8.0b	8.2ab	-
No. of shoots	-		14.0a	15.4a	17.3a	14.0a	-
Shoot length (cm)	-		17.1a	16.9a	15.8a	15.3a	-
P. caperata							
Dry weight (g)	0.7	5.92b	6.95a	7.13a	5.75b	1.74c	Dead
Dry weight (%)	4.6	7.9a	7.0b	7.0b	6.5b	7.9a	-
No of flowers	0	4.7b	16.4a	15.2a	12.8a	0.0b	-
P. obstusifolia							
Dry weight (g)	1.5	6.97b	8.65a	8.98a	9.45a	4.39c	Dead
Dry weight (%)	4.9	5.9c	5.8c	6.0bc	6.2b	6.8a	-
No. of leaves	12	22.7c	38.4b	46.0a	44.6a	14.4d	-
Plant height (cm)	12	14.0c	18.1b	19.9a	20.2a	13.4c	-
S. stolonifera							
Dry weight (g)	0.3	3.27a	3.08a	1.76b	1.02b	Dead	Dead
Dry weight (%)	6.5	9.3b	9.1b	10.2a	10.4a	-	-
Dry weight of runners (g)	0	0.78a	0.79a	0.43b	0.18b	-	-
P. scandens							
Dry weight (g)	1.9	6.22d	9.09c	11.62b	16.23a	14.10a	11.21c
Dry weight (%)	7.9	11.9a	10.5bc	10.8b	11.0b	10.1c	10.9b
No. of leaves	15	23.8e	34.7d	43.8c	53.2b	58.6a	60.1a
Leaf length (cm)	-	24.0c	33.0c	50.4b	65.6a	69.0a	42.5b
S. wallisii							
Dry weight (g)	0.4	1.76b	4.17b	7.13a	7.22a	3.88b	Dead
Dry weight (%)	13.0	14.0c	15.1b	15.9b	15.9b	17.0a	-
No. of leaves	-	19.3d	30.0b	37.0a	37.2a	27.1c	-
Leaf length (cm)	-	11.3c	14.3b	16.8a	16.9a	13.5b	-
Leaf length/ width ratio	-	2.5b	2.36b	2.2c	2.3bc	3.6a	-

creased at increasing temperatures from 21°C, which was the lowest temperature in this experiment (Table 2). Severe leaf necrosis developed at 27°C and the plants died at 30°C. A temperature of about 27°C was optimal for the dry weight production of *C. variegatum*, while higher temperatures reduced the weight and caused severe leaf injuries. Some injuries also developed at 21 and 24°C. The dry weight and shoot length of *N. radicans* were unaffected by temperature in the range 21 to 27°C. However, the frequency of leaf injuries increased with temperature, and the plants died at 33°C.

The optimal temperature for dry weight, number of leaves and height growth was reached at 24°C for *A. commutatum* (Table 3). Higher as well as lower temperatures caused increased leaf

Table 3. The effect of temperature on growth of some foliage plants in Experiment 3. See Table 1 text

	Initial	Temperature (°C) 18	21	24	27	30	33
A. commutatum							
Dry weight (g)	3.3	6.72b	7.74b	10.67a	10.28a	11.43a	6.70b
Dry weight (%)	13	11.2a	11.0c	10.8a	10.6ab	10.2b	8.9c
No. of leaves	13	17.2b	19.6b	23.8a	23.4a	26.1a	19.4b
Height (cm)	-	29.9c	29.8c	33.7b	34.6b	38.2a	32.7b
C. comosum							
Leaf dry weight (g)	1.2	6.71b	6.36b	7.16ab	8.42a	7.07ab	4.71c
Dry weight of runners (g)	0	0.61b	0.94b	0.88b	2.66a	1.66ab	0.32b
Height (cm)	6.9	27.3ab	29.3a	29.3a	29.0ab	28.4ab	26.8b
D. fragrans							
Dry weight (g)	2.0	7.83d	9.22cd	12.04abc	12.32ab	13.47a	9.80bcd
No. of leaves	12.7	11.1d	11.8cd	13.7bc	13.8bc	16.2a	14.4ab
Height (cm)	-	33.3c	34.2bc	37.8ab	38.6a	39.6a	36.3abc
F. japonica							
Dry weight (g)	-	12.04a	12.09a	15.01a	11.70a	4.78b	Dead
Dry weight (%)	11.0	18.1b	17.7b	18.4b	17.0b	21.9a	-
No. of leaves	-	26.2a	29.0a	29.7a	26.9a	16.5b	-
Height (cm)	-	34.2a	35.0a	36.6a	32.8a	22.3b	-
Leaf length/width ratio	-	1.01b	1.00b	1.05b	1.52ab	1.63a	-
M. deliciosa							
Dry weight (g)	0.2	4.95c	7.51b	10.51a	10.86a	9.79a	6.96b
Dry weight (%)	-	12.5a	13.2a	12.3a	13.1a	11.3b	11.2b
No. of leaves	2	7.3c	8.7b	10.3a	10.1a	9.8a	9.2ab
Height (cm)	14	20.1c	25.2b	30.4a	30.1a	32.8a	26.4b

injuries. The dry weight of *C. comosum* increased slightly up to 24-27°C, while plant height was relatively unaffected by temperature. The growth of runners was significantly stimulated by relatively high temperatures (27-30°C). The dry weight and height of *D. fragrans* increased as the temperature increased up to 24°C, while the number of leaves as well as the amount of leaf injury increased up to 30°C. The dry weight, number of leaves and height of *F. japonica* were not influenced by temperature in the range 18 to 27°C. The leaf length/width ratio increased at high temperatures. The dry weight, number of leaves and height of *M. deliciosa* increased up to 24°C and decreased at 33°C, where severe leaf necrosis took place. The optimal temperature for dry weight production of *P. caperata* and *P. obstusifolia* was reached at 21°C. Leaf necrosis developed at 30°C and the plants died at 33°C. The dry weight of *S. stolonifera* was highest at 18-21°C and the plants died at 30°C and above. Maximal dry weight and leaf length of *P. scandens* were obtained at 27°C while number of leaves increased up to 30°C. Leaf necrosis increased above 30°C. A temperature of 24°C was sufficient to give optimal growth of *S. wallisii*, including dry weight, number of leaves and leaf length.

DISCUSSION

The optimum growth temperature varied from < 18 to 24-27°C with the different foliage species (summarized in Table 4). Nine of the 15 species can be grown to advantage at 24°C or higher. Similar results have been obtained with other foliage plants (Mortensen & Larsen 1989). A temperature of 18-22°C has often been used in the commercial production of fo-

Table 4. Optimal growing temperatures for some foliage plants (based on Tables 1-3)

Species	Optimal temperature (°C)
A. commutatum	24-27
B. rex-cultorum	≤21
C. comosum	24-27
C. variegatum	24-27
D. fragrans	24-30
F. japonica	21-27
M. deliciosa	24-27
N. radicans	≤21
P. caperata	21-24
P. obstusifolia	21-27
P. scandens	27-30
R. sinica	≥27
S. wallisii	24-27
S. stolonifera	≤18
S. podophyllum	≥27

liage plants, but much could be gained by increasing this temperature for many species. In the present experiments a constant temperature was maintained day and night. In practice, solar radiation is used to increase the temperature during daytime. Earlier investigations have shown that in general it is the mean temperature, not variations between day and night temperature, that seems to determine the growth rate of foliage plants (Mortensen & Larsen 1989). This means that a high temperature during day or night has a similar effect on plant growth. Increasing the night temperature when insulation curtains are used can sometimes be cheaper than increasing the day temperature.

In the present experiments leaf chlorosis and necrosis developed in different species at low and high temperatures. This could be related to some extent to the temperature stress itself, but also high light levels could have increased the injuries in some species. Foliage plants such as *R. sinica* and *S. podophyllum* grown at 22°C showed no increase in dry weights when the photon flux density was increased from 4 to 8 molm^{-2}day^{-1} (Mortensen & Grimstad 1990). In the present experiments the light conditions at about 10 molm^{-2}day^{-1} were probably higher than needed to give maximal growth. Foliage plants generally seem to require little light for optimal growth (Sandved 1974, 1975, 1976), and sufficient shading is important if leaf injuries are to be avoided. This is important, particularly when the plants are grown at high temperatures. The leaf temperature of unshaded leaves of *M. deliciosa* and *S. stolonifera* on a sunny day in a double acrylic greenhouse was at least 6°C higher than the air temperature compared with a difference of 1-2°C with 50% shading (Mortensen, unpublished data). The leaf temperature will also depend on the air humidity. A high humidity will reduce transpiration and consequently the evaporative cooling of the leaves (Gislerød et al. 1987). Furthermore, if the CO_2 concentration is high this will also reduce the transpiration and the leaf temperature is likely to rise (Mortensen & Gislerød 1989). Therefore, when growing plants at high temperatures it is important to keep the light at a low level; this will then minimize the influence of air humidity and CO_2 concentration on the leaf temperature.

ACKNOWLEDGEMENTS

The author is grateful to Miss M. Siira and Mrs. I. Bratberg for their technical assistance. This work was carried out as part of the project «Energy saving by optimal control of the greenhouse climate» and was financially supported by the National Agricultural Research Council of Norway.

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Effects of temperature, light and CO_2 level on growth and flowering of miniature roses

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The effect of different temperatures (18, 21, 24, 27 and 30°C), supplementary photosynthetic photon flux densities (2, 60 and 120 $\mu molm^{-2}s^{-1}$ PPFD) and CO_2 concentrations (345 and 900 μll^{-1}) on growth and flowering of the miniature rose cultivar Orange Meillandina were studied at 60°N latitude during winter. Growth rate was very low and few flowers developed at the lowest PPFD level irrespective of temperature. When the PPFD level was increased to 60 $\mu molm^{-2}s^{-1}$ plant dry weight and number of flowers increased significantly. A further increase in PPFD level to 120 $\mu molm^{-2}s^{-1}$ gave a significant, but smaller effect. Increasing the temperature from 18 to 30°C at the two highest PPFD caused an almost linear decrease in days until sale (five open flowers), plant dry weight and plant height. The effect of CO_2 concentration (345 and 900 μll^{-1}) was studied at 24°C. CO_2 enrichment increased plant dry weight (15-25%) while there was only a small effect or no effect at all on the other growth parameters.

Key words: CO_2 concentration; flowering; growth; roses; supplementary light; temperature.

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Abbreviation: PPFD = photosynthetic photon flux density.

Miniature or pot roses have become an important greenhouse crop during recent years. At Scandinavia's high latitudes, however, artificial lighting during winter is necessary if efficient production of flower crops is to be obtained, and this practise is well established. The contribution of daylight in December at 60°N corresponds to 10-20 $\mu molm^{-2}s^{-1}$ PPFD provided for 18 h day^{-1} in a greenhouse, which is to low to promote satisfactory plant growth. This raises the question of what level of PPFD should be applied to miniature roses and what temperature in combination with light, would give the optimal result. CO_2 enrichment is commonly used in the winter production of pot plants, so a CO_2 enrichment study was included to see whether the general positive effect of CO_2 also include miniature roses.

MATERIALS AND METHODS

Four rooted cuttings (referred to as a plant) of the miniature rose 'Orange

Meillandina' were potted in 9-cm pots in standard fertilized peat (Floralux). The plants were pinched and placed in six growth chambers (10 m^2 ground area) of double acrylic sheets (Mortensen, 1991). A complete nutrient solution applied two or three times a week contained the nutrient elements in the following concentrations (mg l^{-1}): N, 158; P, 32; K, 209; Ca, 103; Mg, 35; S, 32; Fe, 1.8; Mn, 0.8; Zn, 0.16; Cu, 0.11; B, 0.16; Mo, 0.03 - which gave an electrical conductivity of 1.8 mS cm^{-1}.

Five temperatures (18.0, 21.0, 24.0, 27.0 and 30.0°C) were set and controlled within ±0.5°C of the set point. Supplementary high-pressure sodium light (Philips SON/T) at PPFD levels of 2, 60 and 120 µmol$m^{-2}s^{-1}$ was provided in each chamber for 18 h day^{-1} (03.00-21.00 h). The light was measured at top of the plants by means of a Lambda LI-185B instrument with quantum sensor (400-700 nm). The CO_2 concentration was 900±50 µll^{-1} in five of the chambers, and 345±20 µll^{-1} in one chamber at 24.0°C. The relative air humidity at all temperatures was 65±5%.

Eight plants were used per treatment. Two replicate experiments were carried out, the first started 2. November, 1988, and the second 8. January, 1989. The initial dry weight per pot was 0.50±0.08 g in both replicates. The contribution of daylight at the plant level (about 50% of the outside level) in the two replicate experiments corresponded to 20-30 µmol$m^{-2}s^{-1}$ during 18 h day^{-1} (Meteorological data, Ås, 1988-89).

The plants were harvested when they had at least five open flowers (ready for sale) or after 42 days when the experiments terminated. Plant fresh and dry weight, height, number of shoots, number of flowers and flower buds, and colour of flowers and leaves were recorded. The data were subjected to a split-plot analysis.

RESULTS

The two replicate experiments gave generally the same results (Table 1). The differences included somewhat taller plants (+4 cm), more flowers (+20%), and lower dry weight/no. of flowers ratio in replicate 1 compared with replicate 2. However, the same conclusions were drawn for both replicates; the mean values of both replicates are presented.

At the lowest PPFD the number of open flowers after 42 days was less than five (ready for sale stage) at all temperature levels and were thus not ready for sale. The total number of flowers including the small flower buds, was less than 10 at this light level (Fig. 1). Raising the PPFD level to 60 µmol$m^{-2}s^{-1}$ gave 100% salable plants within the experimental period. Increasing the PPFD from 60 to 120 µmol$m^{-2}s^{-1}$ slightly reduced the days

Table 1. Variance ratios (F) and significance levels for the different variables. The errors a and b mean squares are given. Significance levels: °, P<0.10;*, P<0.05; **, P<0.01; ***, P<0.001

	Df	No. of days until sale	Total no of flow.	Dry wht.	% dry wht.	Height	Dry wht./ no. of flowers ratio
Replicate	1	3.75	9.81*	0.007	1.99	13.7*	11.5*
Temperature	4	52.8**	7.10*	13.7*	1.13	4.61°	2.12
Ms error a	4	32.3	121	9.45	12.8	0.718	0.052
PPFD	2	104***	395***	443***	19.5***	15.5***	8.03**
Temperature x PPFD	8	5.21**	8.79**	19.6**	0.908	4.03*	0.398
Ms error b	10	3.84	38.5	1.41	9.60	0.233	0.071

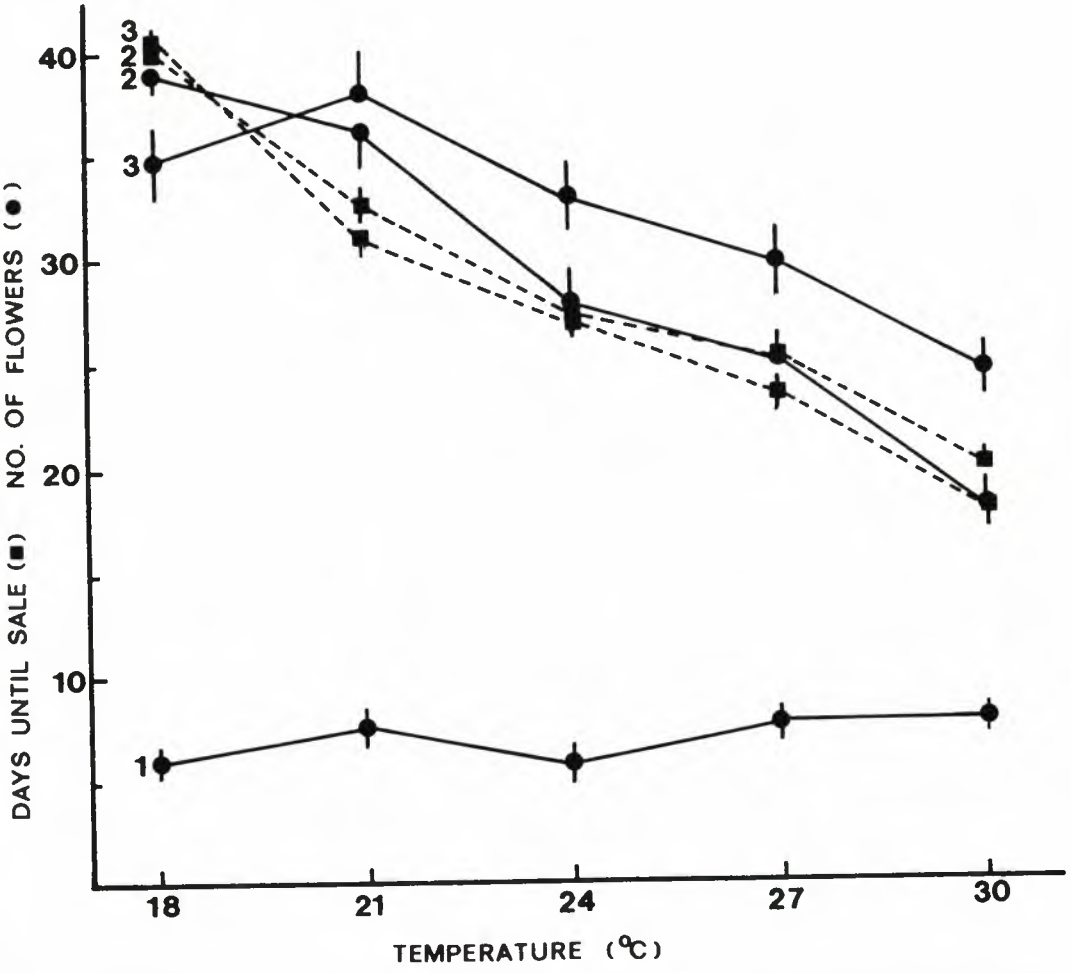

Figure 1. The effect of temperature at 2 (1), 60 (2) and 120 $\mu molm^{-2}s^{-1}$ (3) supplementary light on days until sale and total number of flowers per pot

until sale, and increased the number of flowers (open flowers plus flower buds) at the highest temperature levels (Table 1, Fig. 1). An almost linear decrease in days until sale and number of flowers per plant was observed when the temperature was increased from 18 to 30°C.

Plant dry weight was significantly increased as the PPFD level was increased from 2 to 60 $\mu molm^{-2}s^{-1}$; a further increase of PPFD gave less effect (Table 1, Fig. 2). The dry weight decreased as the temperature increased at the two highest PPFD levels. This was closely related to the decrease in days until sale (time of harvest). There was no decrease in dry weight atributable to temperature at the lowest PPFD level where the plants were harvested after 42 days (did not reach saleable stage). The dry weight percentage were 20.8, 22.3 and 23.9 at 2, 60 and 120 $\mu molm^{-2}s^{-1}$, respectively (Table 1).

The plants were slightly higher at 120 than at 60 $\mu molm^{-2}s^{-1}$, but height decreased as the temperature rose from 18 to 30°C (Table 1, Fig. 2).

The total dry weight/number of flo-

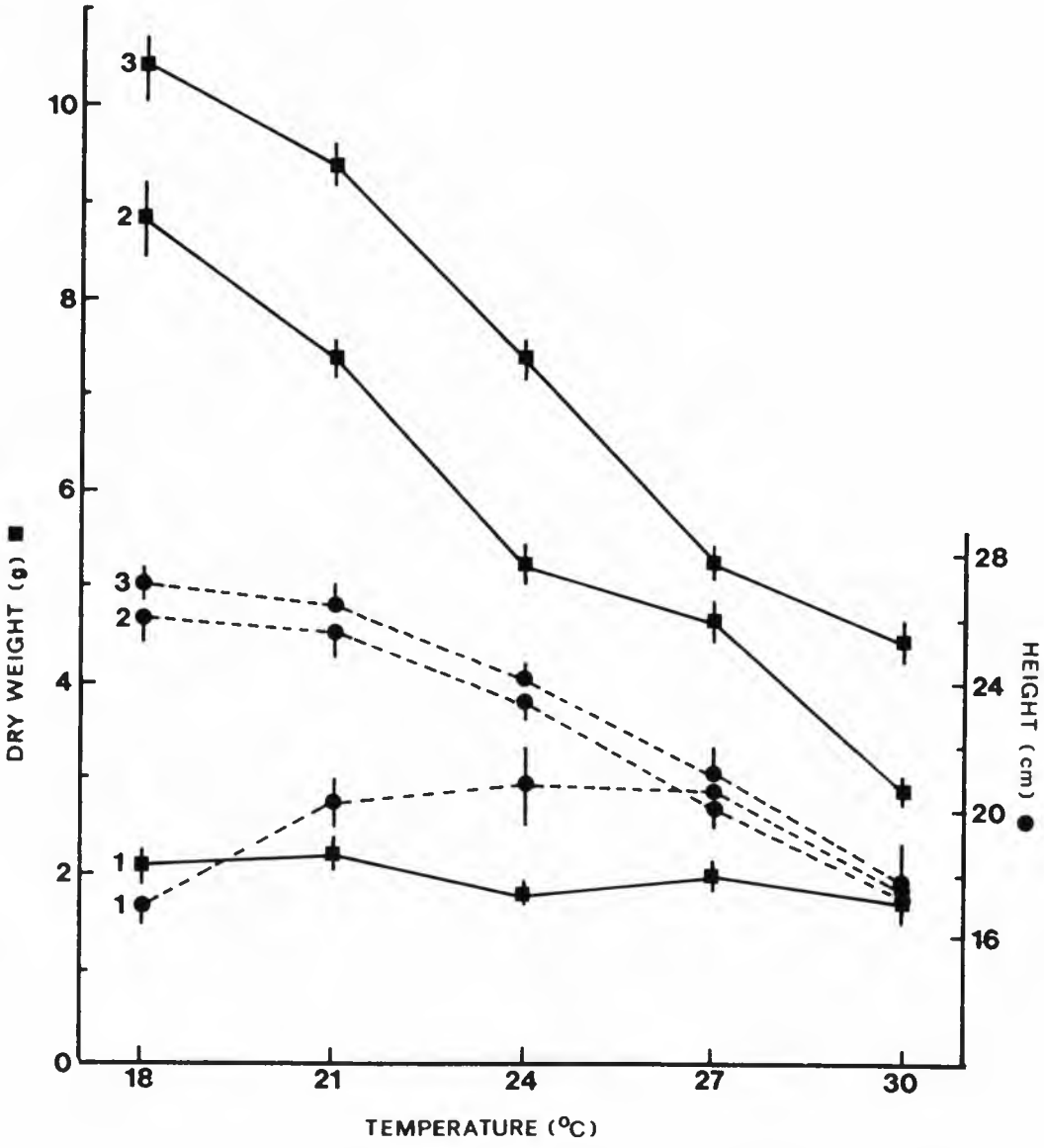

Figure 2. The effect of temperature at 2 (1), 60 (2) and 120 $\mu molm^{-2}s^{-1}$ (3) supplementary light on total dry weight per pot and plant height

wers ratios were significantly affected by the PPFD levels (Table 1), these were 0.36, 0.20 and 0.23 g $flower^{-1}$ at 2, 60 and 120 $\mu molm^{-2}s^{-1}$ PPFD, respectively. Although the effect of temperature was not significant, a tendency towards a decreased ratio was observed as the temperature rose (0.31 g $flower^{-1}$ at 18°C and 0.20 g $flower^{-1}$ at 30°C).

Number of shoots per plant was recorded only in the second replicate; 9.2, 13.8 and 15.7 from low to high PPFD, respectively. Only minor temperature effects were found on this parameter.

Table 2. The effect of CO_2 concentration on growth of miniature roses. Means of three PPFD levels. Significances of main effects and interactions are given

CO_2 conc. (μll^{-1})	No. of days until sale	Total no. of flow.	Dry wht. (g)	% dry wht.	Height (cm)
345	26.9	21.0	3.95	21.7	21.3
900	27.9	22.2	4.80	21.9	22.8
CO_2	*	ns	***	ns	**
CO_2 x PPFD	ns	ns	**	ns	ns

Leaf colour at the two highest PPFD levels was blue-green at 27 - 30°C, and dark-green at 21-24°C. At all other treatments the colour was green or light-green. The colour of the flowers was red from 18 to 24°C and pale red at 27 and 30°C.

CO_2 enrichment delayed the stage of sale one day while total number of flowers was not affected (Table 2). Plant dry weight increased as an average 22% when the CO_2 concentration increased. The absolute effect of CO_2 enrichment increased with PPFD and a significant interaction between PPFD and CO_2 concentration was found (Table 2). Plant height was slightly enhanced by CO_2 application. The number of shoots per pot in replicate 2 was the same at both CO_2 levels irrespective of PPFD level.

DISCUSSION

Our results show that daylight conditions in winter, corresponding to 20-30 $\mu molm^{-2}s^{-1}$ for 18 h day^{-1}, are too low for miniature roses. Supplementary light of 60 $\mu molm^{-2}s^{-1}$ PPFD, however, is sufficient to promote efficient production.

Further increase of PPFD levels give relatively minor effects on flowering and dry weights. Recent results with the same rose cultivar have shown similar optimal PPFD levels for growth in an experiment which started 24 December in Canada (Zieslin & Tsujita 1990). In experiments carried out in the autumn, however, they found increased dry weights and flowering shoot up to about 120 $\mu molm^{-2}s^{-1}$. Previous investigations have shown that about 60 $\mu molm^{-2}s^{-1}$ supplementary light and a photoperiod of 18-20 h can be recommended for foliage plants (Mortensen & Grimstad 1990), which is a similar recommendation to that for pot roses at high lattitudes (60°N). Winter production of pot roses requires lower PPFD levels than cut roses. Recent results show that 100 $\mu molm^{-2}s^{-1}$ during 18 h day^{-1} is a minimum for cut roses, and the yield increases up to at least 300 $\mu molm^{-2}s^{-1}$ supplementary light (Mortensen, unpublished).

As previously shown with cut roses (Moe 1972), increasing the temperature significantly reduces time until flowering and plant height. Pot roses are commonly grown at 18-20°C. At this temperature level the plants will often be too tall, so chemical growth retardants are applied. Much the same effect can be obtained by increasing the temperature and, in addition, the production time will be reduced. However, too high a temperature should be avoided since this will influence the colour of the flower. The effect of growth temperature on subsequent keeping quality in an indoor environment has yet to be investigated. This should be done before high-temperature programmes for miniature roses are introduced commercially.

CO_2 enrichment enhanced the plant dry weight while, time until flowering was little affected, which is in agreement with previous results on cut roses (Mortensen & Moe 1983, Zieslin et al., 1986). No effect of CO_2 enrichment on number of flowers per pot was found in the pre-

sent experiment, which is not in accordance with the general findings with cut roses. The present miniature rose had a similar number of shoots at both CO_2 levels and blind shoots did not constitute a problem as they do with cut roses.

ACKNOWLEDGEMENT

The author thanks Mrs. I. Brattberg for her technical assistance. This work was supported by a grant from the National Agricultural Research Council of Norway.

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Methods of establishing grass/clover swards

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Two N rates in the sowing year, three clover species (*T. pratense* L., *T. hybridum* L., *T. repens* L.), and two sowing methods, with or without cover crop, were investigated in seven trials at five sites. The N rate had the most pronounced negative effect on clover content in the sowing year. Shallow drilling tended to be the best sowing method under dry conditions, whereas broadcasting was best under wet conditions and heavy soils. The use of a cover crop reduced the content of weeds in the sowing year.

Key words: Clover species, botanical composition, cover crop, nitrogen rates, sowing methods, stolon length.

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At the present time few farmers in Norway have the confidence to rely on clover as a basis for cattle and sheep production. Legumes are considered to be difficult to establish, manage and conserve. Because of over-production and quota restrictions, farmers are, however, under pressure to reduce their input costs. In the last few years, the cost of inputs such as N fertilizer has greatly increased (environment tax), whereas product prices have been fairly stable. In this situation the use of clover as a source of nitrogen ought to be of great interest, both in pasture production and in swards for conservation. This paper presents results of experiments on different methods of establishing grass/clover swards

Table 1. Mean climate and soil data at the five experimental sites

Sites	Latitude °N	Climate, May-Sep. Rainfall mm	Temp. °C	Soil pH	P-AL	K-AL	Type	No. of trials
Vågønes	67	410	10.3	5.5	12	15	Sand	1
Tjøtta	66	460	11.8	7.2	22	10	Sand	1
Kvithamar	64	360	11.8	5.7	12	8	Sand	2
Apelsvoll	61	325	12.4	6.1	8	8	Sandy loam	1
Særheim	59	470	12.8	6.2	7	15	Sandy loam	2

MATERIAL AND METHODS

During 1987-88 seven trials were established at five sites. Some data from the sites are listed in Table 1.

A split plot design was used in order to examine nitrogen application rate in the sowing year, species of clover and sowing method. Sowing method and species were allotted to subplots and N rate to whole plots. In six trials one (of 2) replicate was established with a cover crop of early heading barley (drilled, 80 kg ha $^{-1}$ before sowing of grass/clover seed). No herbicides were applied during the sowing year.

The following treatments were investigated:

A. N rates in sowing year
N70(40+30) : 70 kg N ha^{-1} year^{-1}
N210(120+90) : 210 kg N ha^{-1} year^{-1}

Basic fertilizer: 40 kg P and 150 kg K per hectare. In the first harvest year all plots received 70 kg N ha^{-1}

B. Species of clover and seeding rate
Red clover 'Molstad 2n' (*Trifolium pratense* L.) 7 kg ha^{-1}
Alsike clover 'Alpo 4n' (*Trifolium hybridum* L.) 5 kg ha^{-1}
White clover 'Milka 2n' (*Trifolium repens* L.) 4 kg ha^{-1}

All species were spring sown in a mixture with 10 kg timothy (Phleum pratense L.) 'Bodin' per hectare.

C. Sowing method for clover
Drilled (1-2 cm), ring-rolled
Broadcast, ring-rolled

Broadcasting of clover seed was simulated by lifting the seed tubes 15 cm above the soil surface.

During the sowing year a first cut was taken at early heading of barley (1 July) and a second cut at the end of August. Two cuts were taken in the first harvest year (mean dates 5 June and 10 August).

RESULTS

Clover content
The proportion of clover in the sowing year was recorded at the end of August (sorted samples) and at first cut in the harvest year (visual assessment). No significant two- or three-factor interactions were recorded. Main effects are listed in Table 2.

The N rate had the most pronounced negative effect on clover content in the sowing year. Apart from at Kvithamar and Vågønes, where the two N rates were also applied in the harvest year, the N effect was greatly reduced in the harvest year. Of all three species, swards with white clover contained the lowest proportion of clover both in the sowing year and in the harvest year. Strong competition from timothy (late harvest) was the main reason for the low proportion of white clover in the harvest year. In individual trials, sowing method had no significant effect on proportion of clover (Table 2). However, a positive trend for drilling was observed under dry conditions on sandy soils (Vågønes, Tjøtta, Apelsvoll), whereas a negative trend was noticed on heavier soils and under wet conditions (Kvithamar, Særheim).

On average the high N rate reduced the content of clover whereas the proportion of timothy and weeds increased (Table 3). Of the legumes, white clover comprised the lowest and red clover the highest proportion of the herbage in autumn. The use of a cover crop reduced the content of timothy and weeds. About 20% barley was recorded in the regrowth after the first cut (Table 3). No significant species x N interaction was recorded, but white clover tended ($P = 0.10$) to be more sensitive to high N rates than the other clover species (Table 4). No sowing method x clover species interaction was observed.

Table 2. Content of clover (%) in autumn of sowing year (S) and at first cut in the harvest year (H) at different sites

Factor	Vågønes S	Vågønes H	Tjøtta S	Tjøtta H	Kvithamar S	Kvithamar H	Apelsvoll S	Apelsvoll H	Særheim S	Særheim H
N kg/ha:										
70	10	27	48	15	68	32	88	23	48	20
210	5	14	26	13	32	19	61	18	28	18
LSD .05	ns.	ns.	ns.	ns.	10	5	ns.	ns.	11	ns.
Species:										
Red clover	10	31	47	31	61	46	81	38	43	29
Alsike	8	22	42	9	43	28	71	17	47	20
White clover	5	8	23	2	47	4	72	7	25	7
LSD.05	4	10	15	12	12	6	ns.	18	14	4
Sowing method:										
Drilled	8	21	38	16	48	28	78	23	35	19
Broadcast	7	20	36	12	52	24	71	18	42	18
LSD.05	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns	ns.	ns.
Cover crop:										
Without	8	18	28	13	48	25	-	-	38	18
With	7	22	46	15	52	27	-	-	39	19

Table 3. Botanical composition at second cut and total DM yield in the sowing year. Means of six trials with cover crop included as a factor

Factor	Percentage in sorted samples Clover	Timothy	Weeds	Barley	DM yield t ha^{-1}
Nitrogen:					
N70	48	27	17	8	4.70
N210	25	41	23	11	5.15
LSD .05	6	7	6	ns.	0.25
Species:					
Red clover	44	28	19	9	5.10
Alsike	38	37	18	8	4.90
White clover	29	37	23	11	4.80
LSD.05	5	6	ns.	ns.	ns.
Sowing method:					
Drilled	35	34	21	10	4.90
Broadcast	38	33	19	9	4.90
LSD.05	ns.	ns.	ns.	ns.	ns.
Cover crop:					
Without	35	39	26	0	3.90
With	39	28	14	19	6.00
LSD .05	ns.	7	6	7	0.25

Table 4. Species x nitrogen interaction on percentage of clover in autumn of sowing year. Means of six trials

Species	Nitrogen N70	N210	Difference
Red clover	53	35	-18
Alsike	49	27	-22
White clover	44	13	-31

Table 5. Cover crop x N rate interaction. Percentage of clover in autumn of sowing year. Means of six trials

N kg/ha	Cover crop Without	With	Difference
70	44	53	+9
210	26	25	-1

A cover crop also tended (P = 0.08) to have a positive effect on clover content at low N supply, whereas no such effect was observed at the high N rate (Table 5).

DM Yield

No significant interactions between species and the other factors on total DM yield were detected. The high N rate and use of a cover crop gave significant yield increases (Table 3).

As expected, the improvement in yield to nitrogen was better with or without cover crop as follows (t ha^{-1}):

Cover crop	N70	N210
Without	3.80	+0.18
With	5.60	+0.73

White clover growth

At Særheim additional recordings were made by taking turf core samples (0.5 x 0.5m) from white clover plots. Length of stolon, dry weight of above ground biomass (stolon + petioles + leaves) and number of growing points (apices) were recorded. No significant effect of treatments was detected. However, the number of apices tended to be highest at low N rates, on broadcast plots and on plots with cover crop in the sowing year. Stolon length tended also to be longer on plots with cover crop (Table 6).

Table 6. Length of stolon, dry weight of above ground clover biomass (stolon + petioles + leaves) and number of growing points (apices). Data collected on 5 September first harvest year. Means of two trials at Særheim

Factor	Stolon length m m^{-2}	Dry weight g m^{-2}	Growing points No m^{-2}
N kg/ha:			
70	68.8	188	1660
210	67.2	172	1580
Significance	ns.	ns.	P=0.10
Sowing method:			
Drilled	68.6	196	1510
Broadcast	67.6	168	1740
Significance	ns.	ns.	P=0.17
Cover crop:			
Without	61.7	164	1480
With	74.5	196	1760
Significance	P=0.14	ns.	P=0.11

DISCUSSION

The content of clover in the sowing year was lowest at the northernmost site (Vågønes) and highest at Apelsvoll. As expected the basic sand at Tjøtta was favourable for clover growing. On sites with equal N rates in the first harvest year (Tjøtta, Apelsvoll, Særheim) the effect of different N rates in the sowing year on the clover content had almost disappeared by the first cut in the harvest year. The same result was also noticed in Danish trials (Dam Kofoed & Søndergård Klausen 1970). The small proportion of white clover in the harvest year was due to strong competition from timothy. Recent trial work indicates that to reduce competition from timothy the first cut ought to be taken two weeks before heading (20-30 cm grass height) (Øyen, unpublished results).

The conclusion drawn from these re-

sults is that shallow drilling is the safest sowing method under dry conditions, whereas broadcasting is best under wet conditions and heavy soils. In the UK broadcasting is recommended for white clover (Sheldrick et al. 1987b, Frame & Newbold 1984).

The use of a cover crop seems to be favourable for establishing clover under Norwegian condition, and it was found that barley reduced the content of both timothy and weeds in the sowing year. The results also indicated that barley suppressed clover growth less than timothy and weeds. Recent work in Germany shows that oats as a cover crop suppres sed white clover growth less than spring wheat (Lex 1989).

Stolon development was extensive in the autumn in the first harvest year (60-70 m per square metre). Similar figures are noted in UK trials (Sheldrick et al. 1987a).

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Seed production of smooth meadow grass (*Poa pratensis* L.) as influenced by soil type, pH and compaction

I. Chemical and physical soil characteristics

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Aamlid, T.S. 1991. Seed production of smooth meadow grass (*Poa pratensis* L.) as influenced by soil type, pH and compaction. I. Chemical and physical soil characteristics. Norwegian Journal of Agricultural Sciences 5: 307-320. ISSN 5341.

A laboratory incubation experiment was conducted in order to determine the amounts of H_2SO_4 and CaO required to achieve the target pH values 4.6, 5.8 and 7.0 in four experimental fields. Samples were taken for pH measurement at increasing time intervals during a two-year incubation period. In the short term scale, the laboratory experiment underestimated the amounts of lime required to attain a pH of 7.0 in the field. However, whilst pH remained fairly stable in the field after liming, it decreased with time in the laboratory. Acidification caused an abrupt fall in pH, but unlike laboratory results, field pH recovered by approximately 0.5 units within a few months. pH elevation resulted in a slightly decreased potential cation exchange capacity (CEC) and penetration resistance, but exchangeable Mg^{2+} and Ca^{2+}, base saturation and soil water capacity were increased. Compaction resulted in increased penetration resistance, but reduced porosity, notably the content of coarse, air-filled pores. Soil NO_3^- tended to increase with liming on a sandy loam and decrease with compaction on silty loams. In two fields the reduction in bulk density as a result of liming was more marked on uncompacted than on compacted plots.

Key words: Acidification, buffers, cations, incubation, ion exchange capacity, liming, soil air relations, soil pore system, soil strength.

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Most Norwegian soils are inherently acid because of parent material and climate, and liming is therefore a very essential means of increasing plant productivity. Traditionally, the lime requirement of Norwegian soils has been determined by pH measurements, in some cases in suspensions of 0.01 M $CaCl_2$, but most

commonly in distilled water at a soil:water volume/volume ratio equal to 1:2.5. Although such pH analyses are rapid and cheap and well fitted for routine purposes, they are somewhat disadvantageous in that they do not account for the buffer capacity of the soils, and must therefore be interpreted on the basis of texture and organic matter content. Alternative methods include determination of exchangeable acidity or percent base saturation (Wiklander 1968, Vigerust 1970), application of various buffer solutions (Svensson 1981, Erstad 1990), or determination of buffer percent curves (Bergseth 1985). For mineral soils, Vigerust (1970) found that percent base saturation was the method best correlated with yield response to lime, and he suggested a simplified procedure to determine this parameter in routine analyses.

In Norwegian liming experiments (e.g. Pestalozzi 1970, Hovde 1973, Håland 1984, 1985), most attention has been paid to liming materials, rates and application frequencies, and measured pH values have usually been taken as results rather than as predetermined experimental treatments. This implies that within the same lime treatment, a great variation in soil pH might have been found among different experimental fields. The work by Semb (1977) represented an alternative approach: He aimed at achieving four particular base saturation levels on all experimental fields, and, based on chemical analyses and experience with previous lime applications, he calculated the exact amounts of CaO needed.

The main objective of the research described in this report was to examine the effect of soil compaction and three predetermined pH values - 4.6, 5.8 and 7.0 - on seed production of smooth meadow grass. In part I the results of a laboratory incubation experiment are compared with pH and other chemical characteristics obtained in the field. The effects of acidification and liming of soil physical properties are also highlighted.

Table 1. Bulk density (BD), textural composition, organic matter content (OM)[1], P-AL, K-AL, Mg-AL, NH_4OAc exchangeable cations and hydrogen, cation exchange capacity (CEC) and base saturation (BS) of soils from Landvik (soils 1, 2, 5 and 6) and Leirsund/Hellerud (soils 3, 4 and 7)

Soil	BD	Sand	Silt	Clay	OM	pH(H_2O)	P-AL	K-AL	Mg-AL	Na	K	Mg	Ca	H	CEC	BS
	kg dm^{-3}	%	%	%	%		mg/100g			meq/100g						%
1	1.25	72	23	5	8.9	5.2	24	7	3	0.1	0.1	0.3	0.9	10.0	11.3	12
2	0.99	12	78	10	7.5	6.5	15	10	13	0.1	0.1	0.8	4.0	6.4	11.5	44
3	1.32	46	46	8	2.7	7.6	27	7	5	0.1	0.1	0.2	4.4	0.0	4.8	100
4	1.00	11	64	25	6.5	5.7	6	21	4	0.1	0.3	0.2	3.4	9.3	13.4	30
5		67	25	8	2.3	5.7	15	8								
6		26	61	13	7.9	5.7	10	14								
7		7	61	32	4.5	6.1	13	11								

1) % OM = % ignition loss - (1 + (0.05 • % clay)) (Riley 1979)

Table 2. Quantities of 97% H_2SO_4 or CaO added to soils 1-4 in a laboratory incubation experiment

Soil	H_2SO_4 (Mg ha^{-1})								CaO (Mg ha^{-1})			
1					6.0	4.5	3.0	1.5	0	2.0	4.0	6.0	8.0
2					16.0	12.0	8.0	4.0	0	1.0	2.0	3.0	4.0
3	24.0	21.0	18.0	15.0	12.0	9.0	6.0	3.0	0				
4					12.0	9.0	6.0	3.0	0	1.5	3.0	4.5	6.0

MATERIALS AND METHODS

General

A pH-compaction-cultivar experiment was established at Landvik (280 km southwest of Oslo; fields/soils 1-2) and at Leirsund/Hellerud (30 km northeast of Oslo; fields/soils 3-4) in 1987 and one compaction-cultivar experiment initiated at Landvik (fields/soils 5-6) and at Hellerud (field/soil 7) in 1988. Since widely different soil reaction values prevailed on fields 1-4 at the outset of the experiment, pH adjustments by application of H_2SO_4 and CaO were required. In order to determine the quantities needed to achieve the target reaction values, a laboratory incubation experiment was conducted prior to acidification and liming of the fields.

Laboratory incubation experiment

In September 1986, 5 kg soil was taken into the laboratory from each of four experimental fields. After chemical and mechanical analyses (Table 1), 250 g dry, sieved (<2 mm) soil was mixed with various amounts of diluted H_2SO_4 or pure $CaCO_3$ (Table 2) and packed into narrow glasses, two parallels per treatment. Room temperature was kept at 20°C and the water content at 60% of field capacity at free drainage. Samples for pH(H_2O) determination were taken after 7, 21, 42, 88, 192, 390 and 764 days. The soil was allowed to dry for approximately one week before sampling by removing the plastic film covering the glasses.

pH-compaction-cultivar experiment (fields 1-4)

The design was a four replicate split-split-plot comprising pH on the main plots, compaction on the subplots and two cultivars on the sub-subplots. Sulphuric acid and burnt (Hellerud, 98% CaO) or slaked (Landvik, 72% CaO) lime were applied and mixed into the soils with a rotary hoe in April/May 1987. In order to prevent a gradual rise in pH due to leaching of H_2SO_4, a certain amount of elementary sulphur was also added to the most acid plots (Table 3). Three to four weeks later, the fields were harrowed and rolled using a Cambridge roller (uncompacted subplots) or wheel track by wheel track using medium-sized (23-25 kN) tractors (compacted subplots). Depending

Table 3. Quantities (Mg ha^{-1}) of 97% H_2SO_4, elementary sulphur and CaO applied in April/May and August 1987 to achieve target pH values of 4.6, 5.8 and 7.0 in four experimental fields

	Field 1			Field 2			Field 3			Field 4		
	4.6	5.8	7.0	4.6	5.8	7.0	4.6	5.8	7.0	4.6	5.8	7.0
April/May:												
H_2SO_4	1.20	-	-	6.00	1.80	-	16.00	9.00	-	4.00	-	-
Elem. S	0.47	-	-	0.34	-	-	0.41	-	-	0.41	-	-
CaO	-	2.00	10.00	-	-	4.00	-	-	-		0.70	6.00
August:												
CaO	-	1.83	0.95	-	-	0.96	0.41	1.36	1.34	-	0.22	1.37

on the soil water content, the number of compactions was one on field 2 and two on fields 1, 3 and 4. After seeding, all plots were rolled with a Cambridge roller.

In the year of establishment and also in the seed production years, all fields received 30-40 kg nitrogen ha^{-1} in NPK fertilizer 14-6-16 or 16-7-12 and 50 kg N ha^{-1} in $Ca(NO_3)_2$.

Soil samples for chemical analyses were taken from depths of 0-20 cm on each compaction subplot in July and October 1987, October 1988 and August 1989. Whilst only pH was determined in the first three series, the 1989 analyses included K-AL, Mg-AL, Ca-AL, P-AL, NO_3- and NH_4OAc exchangeable cations and hydrogen. Nitrate was determined in samples from two replicates per field; the other parameters were determined in all samples.

The soil reaction values measured two months after acidification and liming indicated that the two higher pH levels were generally too low in relation to their target values, therefore a supplemental surface liming with finely graded, Danish chalk lime was undertaken in August 1987 (Table 3). In the same month an additional wheeling treatment (1-2 compactions) was implemented, prior to soil physical analyses. In 1988 and 1989, compacted plots were trafficked one or two times in August, after penetrometer measurements.

In August 1987, 100 cm^3 cylinders were taken from undisturbed soil at 5-10 cm and 20-25 cm depths. For all combinations of pH and compaction, three cylinders were taken per depth within a 1 m^2 area in one replicate per field. Bulk density and pore size distribution were determined by conventional pF techniques, assuming that total porosity was equal to the water content at full saturation (Riley 1979). Air permeability was measured in accordance with Green & Fordham (1975).

Soil penetration resistance was assessed in August 1987, 1988 and 1989 as described by Aamlid (1990).

Compaction-cultivar experiment (fields 5-7)

The methods followed were similar to those described above for compaction and physical soil analyses. Soil data are briefly recorded in Table 1. The design was a split-plot, with compaction on main plots and cultivars on subplots.

RESULTS

Laboratory incubation experiment

pH determination seven days after incubation gave typical sigmoid response curves for soils 1, 2 and 4 (Figure 1a). Although there was a slow increase in pH values with time for the most acid treatment (Figure 2), the curvilinear pattern persisted even after 764 days for samples which had received sulphuric acid (Figure 1b). On the other hand, buffering against liming increased substantially with time, hence, the upper part of the response curves gradually became more linear. For soils 1, 2 and 4 the pH levels of untreated samples fell throughout the experimental period.

Field experiments

Chemical conditions

In fields 1, 2 and 4, the highest liming rates elevated pH to the 6.5-7.0 range (Figure 3). Application of sulphuric acid caused an abrupt fall in soil reaction, but in the course of the first year pH recovered by 0.2-0.8 units. On the other hand, soil reaction was generally lower in August 1989 than in October 1988.

In field 3, the two higher pH levels were far below their target values, notably in the first year after acidification.

Whilst no significant difference in K-AL values could be detected between pH levels, acidification strongly reduced the content of Mg^{2+} and particularly Ca^{2+} both in the AL extract and after extrac-

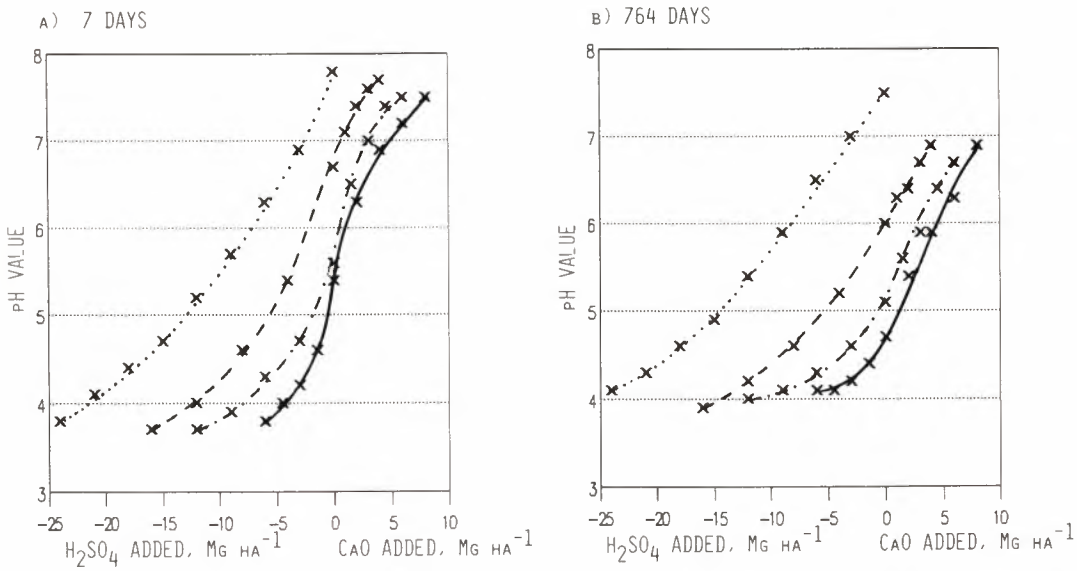

Figure 1. pH values measured in a laboratory experiment after (a) 7 and (b) 764 days of incubation of soils 1 (———), 2 (– – – –), 3 (.....) and 4 (----•----) with various amounts of H_2SO_4 and CaO

tion with NH_4OAc (Table 4). However, because the increase in titratable acidity after acidification was greater than the diminution of exchangeable cations, a negative relationship existed between soil pH and cation exchange capacity (CEC).

Based on soil samples taken in August 1989, the following curvilinear regression was established between pH and percent base saturation (BS): $pH(H_2O) = 4.03 + 0.074\ BS - 0.0005\ BS^2$ ($R^2 = 0.93$). The simple correlations between the content of exchangeable cations and their corresponding AL values were 0.92, 0.98 and 0.97 for calcium, magnesium and potassium, respectively.

Neither P-AL nor soil nitrate was significantly affected by pH alterations in any of the fields. Nevertheless, both characters tended to increase after liming in field 1 ($P = 0.37$ and $P = 0.09$, respectively). Field 3 had a rather low nitrate content and a great irregular variation in P-AL values.

Though tractor traffic never influenced soil chemical properties significantly, the nitrate content was 47% higher in uncompacted than in compacted plots in field 2 and 65% higher in field 4 ($P = 0.25$ and $P = 0.07$, respectively).

Physical conditions

With a few exceptions, pH elevation lowered soil penetration resistance both at 0-10 and at 10-20 cm soil depths (Table 5). The effect was significant in fields 1 and 3. Compaction increased soil strength by 48-95% in the 10-cm surface layer and by 24-53% at a 10-20 cm depth. The pH-compaction interaction was generally insignificant.

Except for the 20-25 cm layer in field 1, compaction increased bulk density in all fields. The effect was generally most marked close to the soil surface. The impact of pH was less evident: at 5-10 cm depths in fields 1 and 2 liming from target pH 5.8 to target pH 7.0 reduced bulk density clearly only on uncompacted

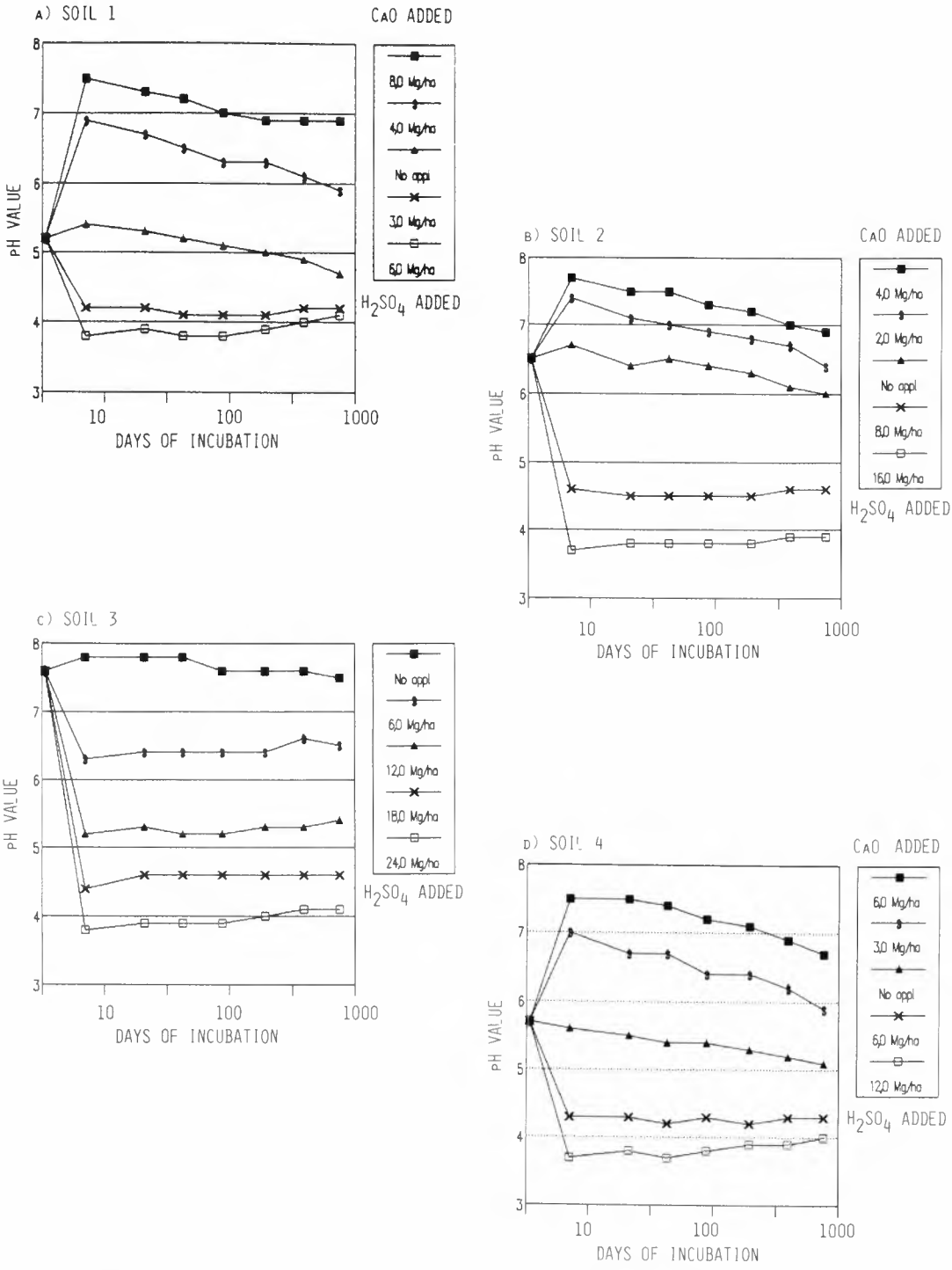

Figure 2. Time courses of pH in soils 1-4 after incubation with various amounts of H_2SO_4 and CaO in a laboratory experiment

Table 4. K-AL, Mg-AL, Ca-AL, P-AL, nitrate, NH_4OAc-exchangeable cations and hydrogen, cation exchange capacity (CEC) and base saturation (BS) at three target pH values in four experimental fields, 28 months after acidification/liming. Means of two compaction treatments

	K-AL	Mg-AL	Ca-AL	P-AL	NO_3	Na	K	Mg	Ca	H	CEC	BS
	mg (100g)$^{-1}$					meq (100g)$^{-1}$						%
Field 1												
pH 4.6	6.3	1.4	5.0	20.0	0.33	0.10	0.09	0.06	0.63	12.68	13.57	6.3
5.8	8.3	4.5	75.0	20.5	0.59	0.13	0.12	0.17	2.65	10.53	13.59	22.5
7.0	7.6	5.7	275.6	22.6	0.90	0.14	0.10	0.18	7.54	3.58	11.54	71.6
Sign.[1]	ns	**	***	ns	ns	***	ns	**	***	***	ns	***
$LSD_{0.05}$	.	1.5	55.7	-	-	0.01	-	0.06	0.93	2.94	-	4.2
Field 2												
pH 4.6	10.6	5.7	43.1	10.5	0.25	0.11	0.13	0.24	2.13	12.03	14.63	17.9
5.8	11.2	11.8	81.6	10.4	0.32	0.13	0.14	0.49	3.15	9.23	13.13	30.0
7.0	11.0	11.2	162.4	10.7	0.27	0.13	0.13	0.45	5.30	6.48	12.49	48.3
Sign.	ns	**	***	ns	ns	ns	ns	**	***	***	ns	***
$LSD_{0.05}$	.	2.7	29.6	-	-	-	-	0.12	0.85	2.29	-	7.8
Field 3												
pH 4.6	5.8	1.1	61.6	15.6	0.04	0.09	0.06	0.06	1.15	6.97	8.33	16.6
5.8	6.7	2.6	93.4	21.2	0.07	0.09	0.07	0.11	1.64	5.93	7.85	28.0
7.0	5.8	3.6	103.0	13.6	0.12	0.09	0.06	0.16	2.20	4.21	6.73	39.3
Sign.	ns	*	ns	ns	ns	ns	ns	**	*	ns	ns	ns
$LSD_{0.05}$	-	1.5	-	-	-	-	-	0.05	0.67	-	-	-
Field 4												
pH 4.6	16.0	2.6	30.6	4.8	0.39	0.12	0.17	0.14	1.42	12.54	14.40	12.9
5.8	15.6	4.4	85.1	4.3	0.55	0.12	0.17	0.22	3.06	9.19	12.75	28.0
7.0	15.1	4.2	179.4	4.8	0.49	0.12	0.17	0.19	5.55	5.04	11.07	55.3
Sign.	ns	*	***	ns	ns	ns	ns	*	***	***	**	***
$LSD_{0.05}$	-	1.3	14.8	-	-	-	-	0.06	0.46	1.17	1.50	4.6

[1] In this report, $P \leq 0.001$, $0001 < P \leq 0.01$ and $0.01 < P \leq 0.05$ are denoted by ***, ** and *, respectively

plots (Table 6). By contrast, pH elevation tended to increase the density on uncompacted plots in field 4 (Table 6) and had no effect in field 3.

Tractor traffic reduced total pore volume at depths of 5-10 cm in all fields (Figure 4). Except for fields 5 and 6, the volume of coarse, air-filled pores seemed to be most affected. Whilst compaction increased the content of medium-sized pores (0.2-30 µm) and thus the topsoil water capacity in fields 3 and 4, a clear reduction in the volume of such pores was detected in field 6. At a depth of 20-25 cm the effect of compaction on pore size distribution was highly variable among fields.

Usually pH elevation resulted in a decreased average pore size in both soil layers (Figure 5). At a depth of 5-10 cm the effect was most accentuated in field 1 where the air-filled porosity decreased from 12.1 to 7.0%, whereas the water capacity increased from 26.4 to 32.7%. Uncompacted subplots in field 2 differed from the general pattern as the air-filled porosity of both soil layers increased with pH elevation (Table 7).

For the 20-25 cm soil layer in particular, great discrepancies were found among fields as to the effect of compaction on air permeability (Table 8). The effects of acidification and liming were also very irregular, a consistent trend

Table 5. Penetration resistance (MPa) at 0-10 and 20-25 cm depths in various soil types as influenced by soil pH and compaction. Means of three (fields 1-4) or two (fields 5-7) years' measurements

	Field						
	1 sandy loam	2 silt loam	3 loam	4 silt loam	5 sandy loam	6 silt loam	7 silty clay loam
				0-10 cm			
Target pH:							
4.6	1.44	1.45	1.05	1.09	-	-	-
5.8	1.37	1.47	0.91	0.98	-	-	-
7.0	1.24	1.37	0.96	0.96	-	-	-
Sign.	**	ns	*	ns			
$LSD_{0.05}$	0.08	-	0.08	-			
Compaction							
Uncomp.	1.09	1.07	0.66	0.69	1.83	1.40	0.73
Comp.	1.61	1.78	1.29	1.33	3.11	2.40	1.17
Sign	***	***	***	***	**	*	**
				10-20 cm			
Target pH:							
4.6	1.63	1.56	1.71	1.33	-	-	-
5.8	1.51	1.61	1.40	1.32	-	-	-
7.0	1.42	1.42	1.36	1.23	-	-	-
Sign.	*	ns	*	ns			
$LSD_{0.05}$	0.14	-	0.22				
Compaction:							
Uncomp.	1.36	1.25	1.28	1.06	1.77	1.34	0.80
Comp.	1.69	1.81	1.70	1.53	2.58	1.90	1.22
Sign	***	***	***	***	*	**	*

Table 6. Bulk density (kg dm^{-3}) at 5-10 cm soil depth in fields 1, 2 and 4 as influenced by soil pH and compaction

	Field 1			Field 2			Field 4		
	Uc.	C.	C./Uc.	Uc.	C.	C./Uc.	Uc.	C.	C./Uc.
Target pH									
4.6	1.30	1.44	1.11	1.24	1.26	1.02	1.05	1.32	1.26
5.8	1.31	1.23	0.94	1.28	1.37	1.07	1.04	1.34	1.29
7.0	1.06	1.32	1.25	1.08	1.31	1.21	1.14	1.30	1.14
Mean	1.22	1.33		1.20	1.31		1.08	1.32	

Table 7. Air-filled porosity (volume %) at 5-10 and 20-25 cm depths in field 2 as influenced by soil pH and compaction

	5-10 cm			20-25 cm		
	Target pH			Target pH		
	4.6	5.8	7.0	4.6	5.8	7.0
Uncomp.	3.1	5.5	10.1	3.8	4.2	5.1
Comp.	3.3	2.2	3.7	5.9	4.9	2.7

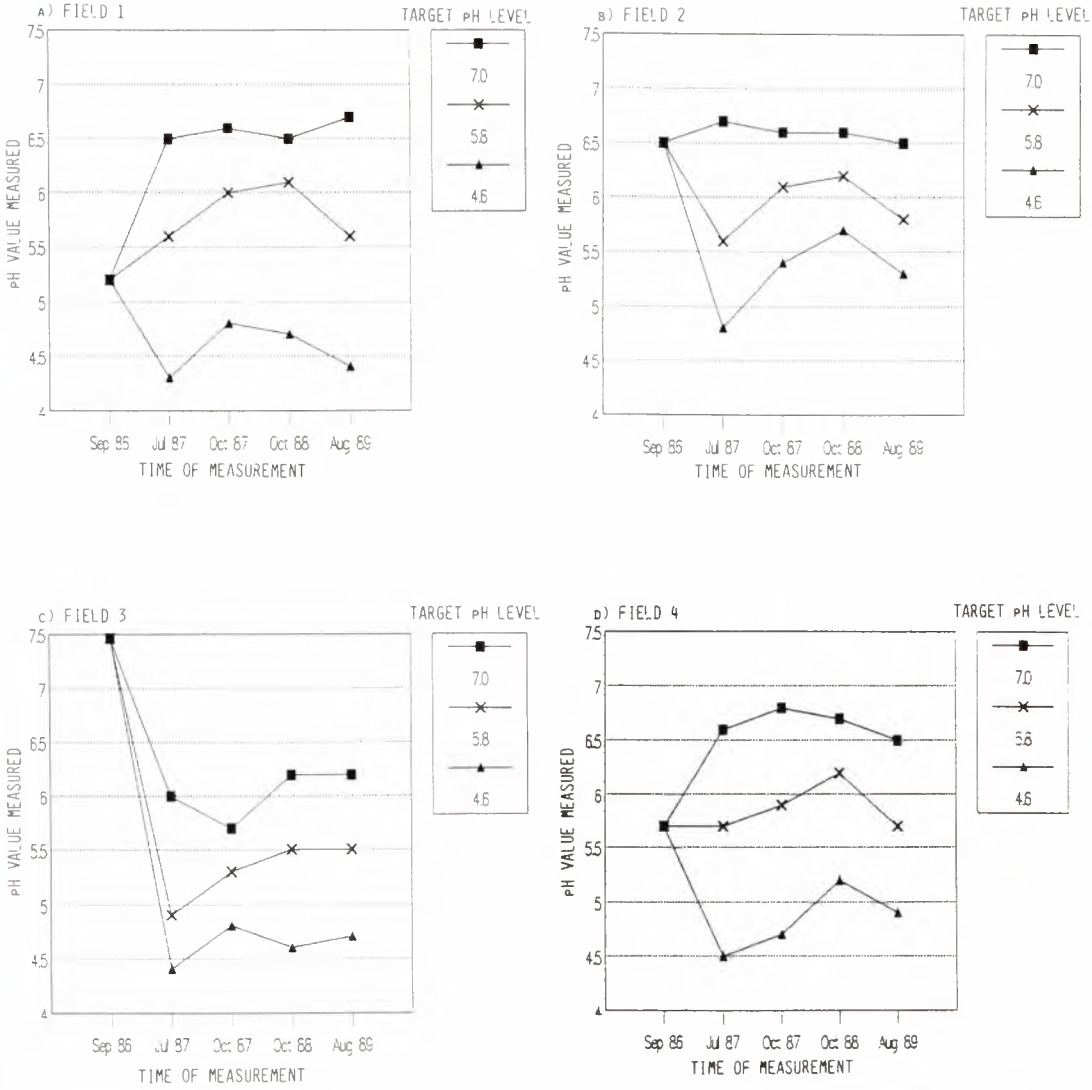

Figure 3. Time courses of measured pH for three target pH values in fields 1-4. Means of two compaction treatments

being detected only at a depth of 5-10 cm in field 1:

	Target pH		
	4.6	5.8	7.0
Uncomp.	4.1	3.4	2.1
Comp.	1.9	1.8	1.2

DISCUSSION

pH alterations in laboratory and field

Soil resistance to abrupt changes in pH is of considerable importance to plants and other living organisms. Because of a great complex of buffer systems, agricul-

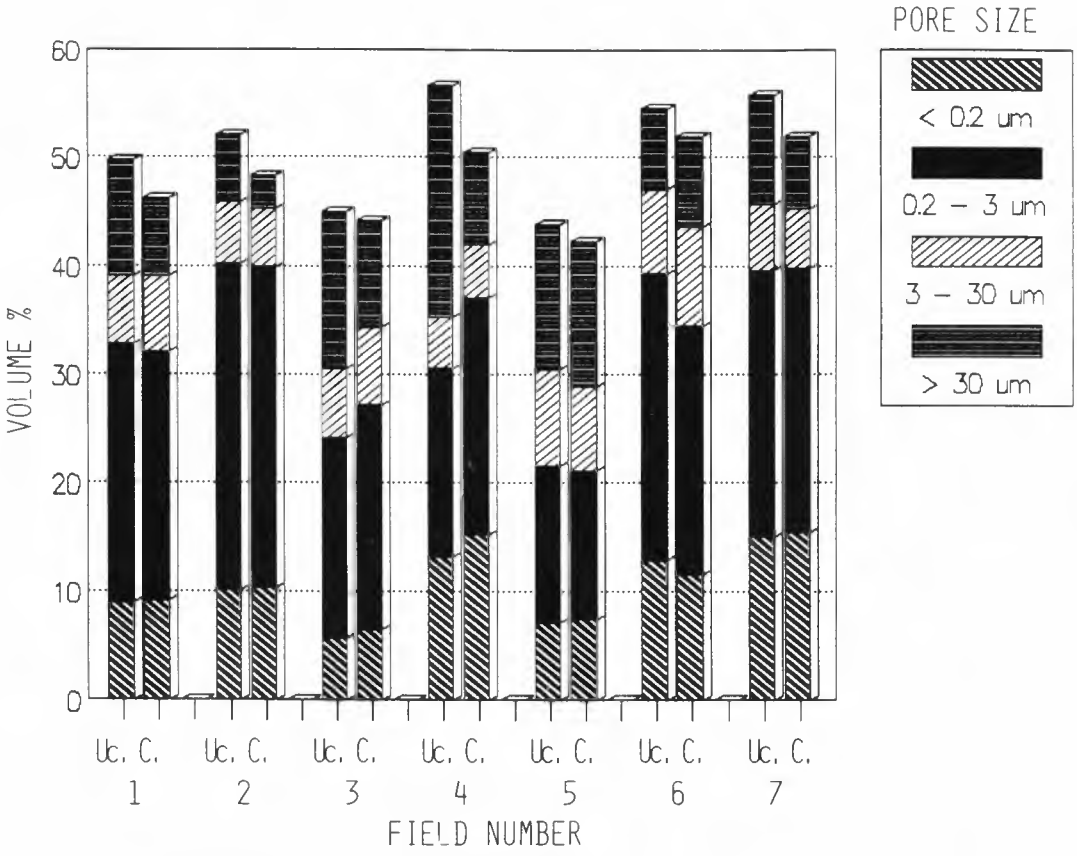

Figure 4. Pore size distribution at 5-10 cm depths in uncompacted (Uc.) and compacted (C.) plots in seven experimental fields. Means of three target pH values (fields 1-4)

tural soils normally behave like weak acids upon addition of base lime or acid (Wiklander 1968, Ulrich 1981, Scheffer & Schachtschabel 1984, Filep & Rédly 1987). The incubation experiment (Figure 1) indicated that the resistance to pH change will increase as extreme values are approached. Whilst the strong buffer capacity at pH < 5 probably reflects neutralization of protons by gradual mineral weathering and dissolution of various complexes of Al-hydroxides, incomplete dissolution of $CaCO_3$ may explain why soil reaction shortly after incubation seemed to level off in the pH range 7.0 to 8.4, the latter as the ultimate carbonate saturation (Ulrich 1981). pH-dependent charges on organic colloids, and on the edges and in the interlayers of clay-sesquioxide complexes probably account for the more or less constant buffer capacity between these extremes (Svensson 1981, Thomas & Hargrove 1984).

Whereas some buffer reactions occur immediately after acidification or liming, others will become more pronounced with time. For example, the slow, but consistent increase in soil reaction after acidification to pH values below 4 must be ascribed to enhanced weathering by protolysis of silicate minerals (Scheffer & Schachtschabel 1984, Murányi 1987). For soils 1,2 and 4 the gradual decrease in the pH of limed and untreated samples was probably a result of soil respiration, mineralization processes like ammonifi-

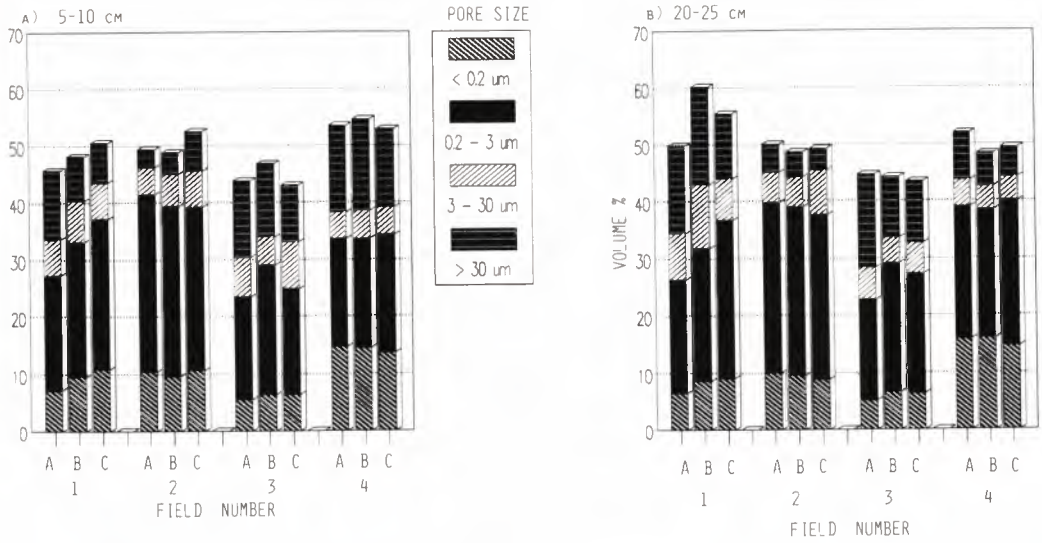

Figure 5. Pore size distribution at two depths in four experimental fields as affected by target pH values 4.6 (A), 5.8 (B) and 7.0 (C). Means of two compaction treatments

cation followed by nitrification and other acidifying reactions associated with organic matter decay by soil micro-organisms (Njøs 1969). An optimal soil water content and a high and stable temperature are factors contributing to higher microbial activity in the laboratory than under field conditions. A low organic matter content probably restricted this activity in soil 3.

Even though the quantities of CaO applied to achieve a neutral soil reaction were generally higher than those indicated by the laboratory experiment (Table 3, Figure 1), the highest pH values recorded in fields 1, 2 and 4 ranged from 6.5 to 6.8 (Figure 3). Similar discrepancies between laboratory and field experiments were observed by Semb (1978) and can chiefly be ascribed to uncertain conversions from weight to area units and to uneven mixing of lime and soil in the field. Besides, at pH values beyond 6.3-6.5 a certain leaching of lime to the subsoil will always occur (Bertilsson 1988). The additional surface liming in August 1987 had probably very little effect on soil pH except for in the 5 cm topsoil layer (Hovde 1973, Håland 1984).

The marked increase in pH during the first months after field acidification must be due to leaching of sulphuric acid. Though the adsorption of SO_4^{2-} normally increases with falling pH (Thomas & Hargrove 1984), the soils have hardly been able to cope with the great quan-

Table 8. Air permeability (um^2) as influenced by compaction in seven experimental fields

	Field						
	1	2	3	4	5	6	7
				5-10 cm			
Uncomp.	3.2	1.5	6.2	12.8	4.1	1.2	15.4
Comp.	1.6	0.3	7.1	3.8	6.7	0.8	2.4
				20-25 cm			
Uncomp.	5.5	1.1	10.4	4.9	5.4	5.1	3.6
Comp.	5.9	0.8	7.8	3.5	9.3	2.3	7.3

tities added in this experiment. The total rainfall for the period July-September 1987 was 459 mm at Landvik (Met. Station, Kjevik) as compared with only 261 mm at Leirsund/Hellerud (Met. Station, Gardermoen); it is therefore not surprising that the rise in pH was generally greater at the former location. It was surmised that oxidation of elementary sulphur would compensate for leaching of sulphuric acid, but this effect has apparently been of minor importance under the present conditions.

Owing to red-ox and dilution effects, the pH(H_2O) value determined for one particular soil will normally increase with increasing water content at the date of sampling. (Scheffer & Schachtschabel 1984). From an irrigation experiment at Landvik Research Station, Ekeberg (1972) documented that the difference between wet and dry samples may amount to as much as 0.5 pH units. In the present investigation pH samples were taken from nearly saturated soils in October 1988 but from rather dry soils in August 1989; this accounts for the general drop in soil reaction in this period.

The reaction values obtained for field 3 were generally far below those expected from the laboratory experiment. This field was located on a fluvial deposit close to the river 'Leirelva', and, unfortunately, parts of it were flooded a couple of times during the experimental period, probably inducing sulphate reduction. Due to variable red-ox potentials, pH differed widely between plots receiving the same acid treatment. The exceptionally high pH recorded in the soil taken into the laboratory in autumn 1986 has obviously not been representative of the whole field, and the quantities of sulphuric acid required to achieve the target pH values were therefore miscalculated.

Cation exchange properties

Though the increase in exchangeable H^+ after acidification to the lowest pH level may be explained by dissolution and removal of Al-hydroxides from collodial sites, the general reduction in CEC caused by pH elevation (Table 4) seems contradictory to earlier Norwegian results (Pestalozzi 1970, Vigerust 1970). However, the potential CEC has little practical relevance, as most of the negative charges on organic colloids and sesquioxide-mineral complexes normally become non-functional as pH decreases. A determination of the effective CEC after extraction with an unbuffered salt solution had likely given a result more representative of the acid soils (Helling et al. 1964, Thomas & Hargrove 1984).

Because of charge, size and hydration characteristics, the strength of adsorption of cations to soil colloids normally decreases in the order: $Al^{3+} > Ca^{2+} > Mg^{2+}$ (Scheffer & Schachtschabel 1984). It is therefore not surprising that calculations of the Ca/Mg ratios from Table 4 generally indicate increasing tendencies with both acidification and liming. Though Mg deficiency is most frequently observed in acid, highly leached soils, application of calcitic lime to moderately acid soils may in some cases induce such deficiency as a result of Ca-Mg antagonism (Kamprath & Foy 1985). Marti (1983) in fact reported a reduction in Mg-AL values after liming with 5-15 Mg CaO ha^{-1}.

Nitrogen and phosphorus

The increase in plant available phosphorus and nitrate after liming in field 1 (Table 4) can most likely be ascribed to a stimulation of microbial activity with a concomitant increase in the turnover rate of soil organic matter (Ekeberg 1973, Hovde 1973, Njøs 1978, Marti 1983, Myhr & Njøs 1983). Nitrification is known to benefit from higher pH values than ammonia formation (Haynes & Swift 1989), but since this is a strictly aerobic process, it may be prevented by lack of oxygen in the soil. In this line Njøs (1978) reported that liming increased the soil nitrate content only when no extraordinary compaction had been conducted. The reason why such interactions were

absent in the present material may be that the soil samples were taken after a long drought period which impaired nitrogen conversion in both uncompacted and compacted plots. In Njøs' experiment, the average NO_3 level was about ten times higher than that in the present one.

Soil physical conditions

It is widely accepted that liming normally improves soil structure. This is partly due to a more favourable environment for micro-organisms and soil fauna, but Ca^{2+} ions will also directly augment formation and consolidation of soil aggregates (Marti 1983, Scheffer & Schachtschabel 1984). Since they are more quickly soluble at high pH values, this direct effect will generally be more significant for burnt and slaked lime than for calcium carbonate (Njøs 1969). However, the present results gave no indication that the harmful effects of tractor traffic on soil structure may be offset by heavy applications of burnt or slaked lime. Rather, the compaction-pH interactions presented in Tables 6 and 7 suggest that the impact of liming will be more marked in loose than in compact soils.

As compared with earlier investigations in which soil strength has been measured with a vane and torquemeter (Njøs 1978, Marti 1983, Myhr & Njøs 1983, Hofstra et al. 1986), the effect of liming on soil penetration resistance was quite pronounced in the present work (Table 5). In concurrence with Taylor et al. (1966) who found a very close relationship ($r = 0.93$) between vane soil strength and penetrometer soil strength, there is reason to believe that this discrepancy is not a question of method, but rather a result of the greater span in soil reaction in the present experiment. Notably in fields 1 and 3, growth was very poor at target pH 4.6, and in these plots little loosening by plant roots occurred.

ACKNOWLEDGEMENTS

The author is indebted to Drs K.J. Erstad and I. Lyngstad for valuable discussions and for providing facilities for the laboratory incubation experiment. Thanks are also expressed to the staff at Kise and Holt Agricultural Research Stations for carrying out the physical and chemical soil analyses and to Professors B. Opsahl and A.O. Skjelvåg for helpful advice and corrections to this manuscript.

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Seed production of smooth meadow grass (*Poa pratensis* L.) as influenced by soil type, pH and compaction

II. Seed yields and other plant characteristics

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Aamlid, T.S. 1991. Seed production of smooth meadow grass (*Poa pratensis* L.) as influenced by soil type, pH and compaction. II. Seed yields and other plant characteristics. Norwegian Journal of Agricultural Sciences 5: 321-338. ISSN 0801-5341.

Ley establishment without cover crop was generally good on light soils except at pH < 5. On heavy soils, compaction improved field germination in a wet season (1987), but had the opposite effect in a dry season (1988). Seed yields increased with pH up to a target value of 7.0 on light soils in the first ley year and on all soils in the second year, but the pH target value of 5.8 appeared to be better for well-established crops on heavy soils in the first and third ley years. Compaction had variable effects on seed yields; the strongest reductions were observed in a second ley year with rather dry weather (1989). At Landvik (58°N) there was a very marked depression in the second year yield for the North Norwegian cultivar 'Lavang'. The newly released cultivar 'Ryss' and breeding materials usually gave higher seed yields than older Norwegian cultivars.

Key words: *Alopecurus geniculatus* L., germination, lodging, plant establishment, *Poa annua* L., production location, yield components.

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The major herbage seed crops in Norway are timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* Huds.) red clover (*Trifolium pratense* L.) and cocksfoot (*Dactylis glomerata* L.). In 1988, the approved acreage for these species was 2336, 485, 272 and 98 ha, respectively (Statens frøkontroll, 1989). The seed acreage for smooth meadow grass (*Poa pratensis* L.) was only 26 ha; 20 ha for the North Norwegian cultivar 'Lavang' and a mere 6 ha for the southern Norwegian cultivar 'Leikra'. Seed yields of both cultivars were rather poor - approximately 200 kg ha^{-1} on average.

Both 'Lavang' and 'Leikra' are fodder

types of smooth meadow grass. For the much more widespread amenity purposes, approximately 300 tonnes of seed are imported annually, mainly from The Netherlands, Denmark and the USA. However, the first Norwegian turf cultivar of smooth meadow grass, 'Ryss', was released in 1990, and in a few years' time, more cultivars can be expected from a breeding programme at Kvithamar Agricultural Research Station, Central Norway. An appreciable increase in the Norwegian smooth meadow grass seed acreage is therefore very likely.

At present one of the major obstacles to smooth meadow grass seed production is infestation by the grass weeds *Poa annua* L. and *Alopecurus geniculatus* L. In 1988, 47 and 77% of Norwegian seed lots of smooth meadow grass were contaminated with *P. annua* and *A. geniculatus*, respectively, and every fourth lot contained more than 1% weed seeds by weight and were thus rejected (L.J. Rustad, Statens frøkontroll). However, extensive research has shown that implementation of the activated carbon band seeding technique will improve seed purity substantially (Synnes 1986); moreover, current experiments with autumn application of herbicides are promising (Skuterud 1990).

There has been extensive discussion as to which geographical region in Norway is best adapted for smooth meadow grass seed production. For most other species, farmers in the district on the west side of the Oslo fiord (Vestfold county) have the largest acreage and obtain the highest seed yields. However, in this area, soils are rather heavy and the establishment of seed fields without a cover crop is often complicated. It has also been speculated that seed yields of rhizome forming grass species will be low on such soils due to compaction and mechanical impedance to rhizome extension. Furthermore, since 'Lavang' and 'Leikra' are adapted to regions with different temperature and photoperiodic regimes, it has been anticipated that the former would need a more northern location for seed production than the latter. The existence of such location-cultivar interactions has indeed been reported by Håbjørg (1979) and Nordestgaard (1983b).

In particular, it is widely known from turf experiments that smooth meadow grass benefits from high soil pH values (Håbjørg 1977). Earlier single plant studies have shown that this is also the case for seed production, although pH elevation from 5.5 to 6.6 was clearly more favourable to herbage than to seed yields (Aamlid 1990b).

The aim of the research described in this report was to clarify choice of location and - in particular - soil type that is best suited for seed production of smooth meadow grass. Moreover, the results of single plant studies on the effects of pH (Aamlid 1990b) and compaction (Aamlid 1990c) needed an evaluation from a more practical point of view.

MATERIAL AND METHODS

A pH-compaction-cultivar experiment was established on a sandy loam and a silt loam (fields 1 and 2, respectively) at Landvik (280 km southwest of Oslo), and on a loam and a silt loam (fields 3 and 4, respectively) at Leirsund/Hellerud (30 km northeast of Oslo) in 1987 (Aamlid 1990d). This experiment comprised only the two fodder cultivars 'Leikra' and 'Lavang'. In a second compaction-cultivar experiment established on a sandy loam and a silt loam at Landvik (fields 5 and 6, respectively) and a silty clay loam at Hellerud (field 7) in 1988, four additional cultivars/populations were included: 'NLH 3', 'Ryss', 'KvEr 03-6-49-2/21' (abbr. 'KvEr 2/21') and 'KvEr 03-5-43-25/24' (abbr. 'KvEr 25/24'). Seeds were kindly donated by Mr S. Foss and Dr C. Holm, Kvithamar Research Station.

All experimental fields were established without a cover crop. Fields 1-4 and 7 were seeded at a rate of 10 kg ha^{-1}

and at a row spacing of 12.5 cm. In fields 5 and 6, 5 kg ha^{-1} and 36 cm were used in conjunction with the carbon band technique (Synnes 1986). Fertilization prior to seeding was always 40 kg N ha^{-1} in a compound fertilizer NPK 16-7-12 or 21-4-10. Field germination was assessed according to a scale from 0 to 9 two months after seeding.

Especially in the rather wet summer of 1987, a great number of weeds germinated. These were partly controlled by chemical means (bromphenoxim and the triple mixture bentazon/MCPA/dichlorprop against dicotyledons; chlortuluron against monocotyledons) and partly by mowing in July/August. In order to qualify the seed for use in future multiplication programmes, plots of 'KvEr 2/21' and 'KvEr 25/24' were hand-weeded in fields 5 and 6, hence weed analyses of these populations are omitted from this report. Autumn dressing in the year of establishment was 50 kg N ha^{-1} applied as $Ca(NO_3)_2$.

In the seed production years 30-40 kg N ha^{-1} in a NPK fertilizer 14-6-16 or 16-7-12 was applied as soon as the ley was trafficable in spring. After full heading, the number of panicles within 0.6 m-0.6 m portable metal frames was counted. The percent lodging was determined immediately before seed harvest in the first part of July. At Leirsund/Hellerud, the sward was cut with a mower and the gross mass dried, weighed and threshed indoors. At Landvik a self-propelled combiner was used, and the straw was weighed within a few days. In 1990 a second threshing operation was conducted on fields 5 and 6 before straw removal. On all fields possible regrowth was harvested during the first week of September, and 50 kg N ha^{-1} was applied as $Ca(NO_3)_2$.

After cleaning, one seed sample per treatment (common for four replicates) was analysed for purity and contamination by seeds of *Poa annua* and *Alopecurus geniculatus* at the Norwegian State Seed Testing Station. Five to eight months after seed harvest, water content, thousand seed weight and germination after 10 and 28 days were determined according to official rules (Statens frøkontroll 1987) in the seed laboratory at Landvik Research Station.

The fields were harvested for seed in two (fields 1, 3, 5, 6 and 7) or three (fields 2 and 4) ley years. Analyses of variance were mostly performed separately for each ley year on each experimental field. For fields 1-4 thousand seed weight, germination and seed purity data were tested against the pH-compaction-cultivar interaction, but, in addition, an overall analysis was conducted for each year with field number as the random variable. For fields 5 and 6, differences between cultivars were also tested against the field-cultivar error term. In this report $P \leq 0.001$, $0.001 < P \leq 0.01$ and $0.01 < P \leq 0.05$ are indicated by ***, ** and *, respectively.

In the yield component analysis, seed number per panicle was calculated from panicle number, thousand seed weight and seed yield.

RESULTS

Plant establishment

Seed germination and seedling growth were generally hampered by low pH values, especially on light soils (fields 1 and 3) (Table 1). Tractor traffic prior to seeding significantly enhanced establishment on heavy soils in 1987 (fields 2 and 4), but was clearly disadvantageous in 1988 (fields 6 and 7). In field 7, germination was negligible after compaction; further studies and seed harvest were therefore restricted to uncompacted plots and will not be reported here. On light soils plants became established slightly better on uncompacted than on compacted plots in both years; however, this effect was significant only in field 3.

Differences between cultivars in field germination were generally small and not consistent from field to field.

Table 1. Plant establishment (scale 0-9; 9 is best) two months after seeding as affected by pH and compaction on sandy loams (fields 1 and 5), loam (field 3), silt loams (fields 2,4 and 6) and silty clay loam (field 7)

	Field						
Target pH	1	2	3	4	5	6	7
4.6	4.0	4.2	1.3	3.9			
5.8	7.8	5.1	3.1	5.2			
7.0	7.6	4.5	5.3	5.8			
Sign.	*	ns	**	ns			
$LSD_{0.05}$	2.4	-	1.9	-			
Uncomp.	7.0	2.1	4.4	2.3	6.8	7.4	6.7
Comp.	6.0	7.0	2.0	7.6	5.9	5.2	-
Sign.	ns	***	*	***	ns	**	-

Seed yield

First ley year

On light soils, seed yields increased significantly up to the highest pH value, irrespective of compaction treatment (Table 2). On heavy soils, yields were higher at target pH 7.0 than at target pH 5.8 only when no compaction had been carried out, the interaction being almost significant ($P=0.07$) in field 2 and clearly significant ($P<0.01$) in field 4 (Figure 1). Whilst 'Lavang' produced two to three times more seed than 'Leikra' at Landvik (fields 1 and 2), the difference was less marked at Hellerud (field 4) and negligible at Leirsund (field 3). The pH-cultivar interaction was significant for all fields, mostly reflecting a much stronger response to the first pH increment in 'Lavang' than in 'Leikra'. For field 1, seed yields increased linearly with pH in 'Leikra', but showed a diminishing response as pH exceeded 5.8 in 'Lavang'. In field 2, 'Leikra' was almost unaffected by the second pH increment; by contrast, 'Lavang' clearly performed best at the intermediate soil reaction level (Figure 2). The compaction-ecotype interactions were generally not significant.

In the compaction-cultivar experi-

Table 2. Main effects of pH, compaction (Uc./C.) and cultivar on seed yields (kg ha^{-1}; 100% purity; 14% water content) of smooth meadow grass in the first (1988), second (1989) and third (1990) ley years on a sandy loam (field 1), loam (field 3) and silt loams (fields 2 and 4)

	Target pH										
	4.6	5.8	7.0	Sign.	$LSD_{0.05}$	Uc.	C.	Sign.	Leikra	Lavang	Sign.
					First ley year (1988)						
Field 1	68	275	359	***	67	240	228	ns	145	332	***
Field 2	195	306	265	ns	-	245	266	ns	164	346	***
Field 3	103	189	319	*	148	206	201	ns	200	207	ns
Field 4	202	279	280	ns	-	216	291	***	217	290	***
					Second ley year (1989)						
Field 1	15	98	133	***	21	95	69	**	83	81	ns
Field 2	89	141	188	*	68	154	126	*	179	100	***
Field 3	56	73	71	ns	-	72	52	ns	74	59	*
Field 4	121	145	217	***	25	217	105	***	121	201	***
					Third ley year (1990)						
Field 2	130	207	223	ns	-	205	168	*	241	132	***
Field 4	61	64	58	ns	-	76	46	***	66	56	**

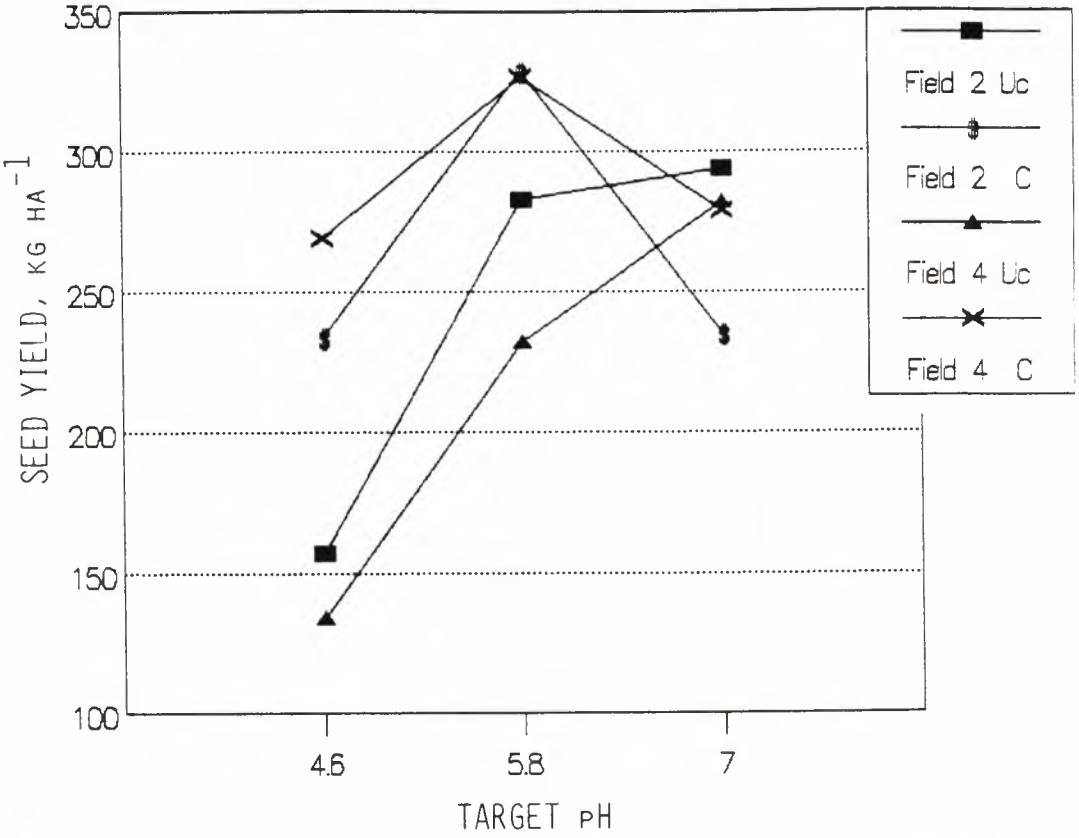

Figure 1. Seed yields (100% purity; 14% water content) of smooth meadow grass in the first ley year (1988) as influenced by soil pH on compacted (C.) and uncompacted (Uc.) subplots in fields 2 and 4 (silt loams)

ment initiated in 1988, tractor wheeling reduced seed yields on the sandy loam but had the opposite effect on the heavier soil (Table 3). The effects were almost significant ($P=0.06$ and $P=0.07$, respectively). On an average for treatments, 'NLH 3' tended ($P=0.11$) to be the highest yielding cultivar, while 'Leikra' appeared to be a rather poor seed producer, inferior to 'Lavang', 'Ryss' and the breeding materials from Kvithamar Research Station (Table 4).

Contrary to the other cultivars, seed yield of 'NLH 3' was not lowered by compaction in field 5 ($P_{interaction}=0.10$). In field 6, a significant compaction-

Table 3. Seed yields (kg ha^{-1}; 100% purity; 14% water content) on field 5 (sandy loam) and field 6 (silt loam) in the first (1989) and second (1990) ley years as influenced by compaction. Means of six cultivars

	1989			1990		
	Uncomp.	Comp.	Sign.	Uncomp.	Comp.	Sign.
Field 5	630	557	ns($P=0.07$)	302	321	ns
Field 6	448	535	ns($P=0.06$)	428	459	ns

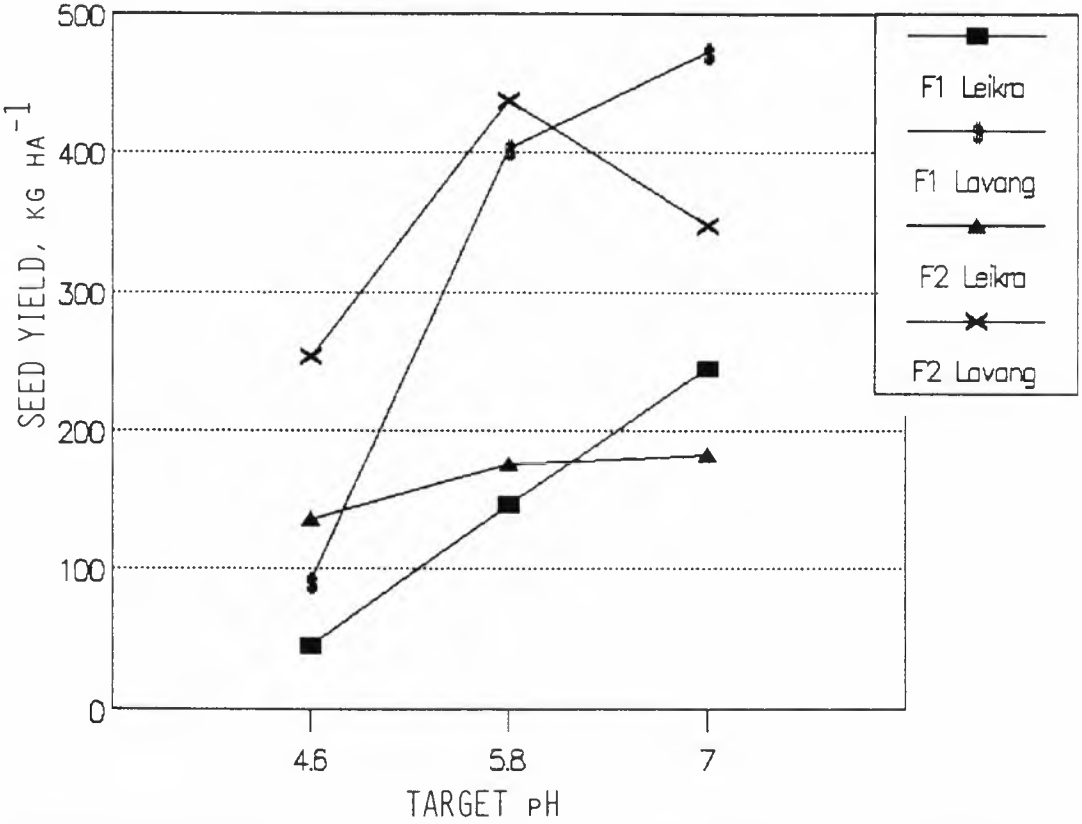

Figure 2. Seed yields (100% purity; 14% water content) of the smooth meadow grass cvs. 'Leikra' and 'Lavang' in the first ley year (1988) as influenced by soil pH in fields 1 (F1) and 2 (F2)

cultivar interaction indicated that 'Leikra' and 'NLH 3' were mostly stimulated by the wheeling treatment (data not shown).

Second ley year

In the pH-compaction-cultivar experiment seed yields dropped markedly from the first to the second ley year (Table 2). The decline was most severe on light soils; for field 3 this can mainly be attributed to invasion of couch grass (*Elytrigia repens* Nevski.). Whilst the yield depression was fairly similar for 'Lavang' and 'Leikra' at Leirsund/Hellerud, the former cultivar appeared to be most affected at Landvik.

With the exception of field 3, seed yields in the second year increased with liming right up to the highest pH value.

Table 4. Seed yields (kg ha^{-1}; 100% purity; 14% water content) of six cultivars of smooth meadow grass in the first (1989) and second (1990) ley years. Means of uncompacted and compacted plots in fields 5 and 6

	Leikra	Lavang	NLH 3	Ryss	KvEr 2/21	KvEr 25/24	Sign.	$LSD_{0.05}$
1989	397	514	777	588	421	558	ns(P=0.11)	-
1990	378	278	582	487	422	513	**	83

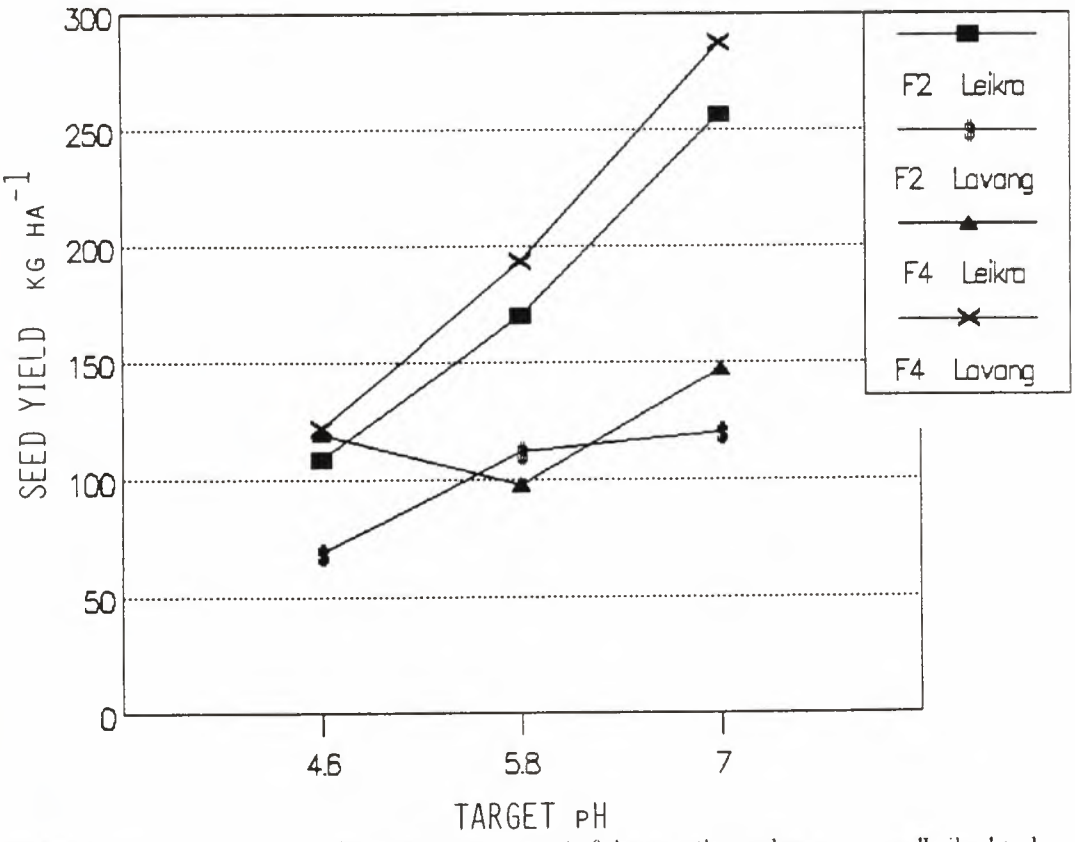

Figure 3. Seed yields (100% purity; 14% water content) of the smooth meadow grass cvs. 'Leikra' and 'Lavang' in the second ley year (1989) as influenced by soil pH in fields 2 (F2) and 4 (F4)

'Leikra' was more responsive than 'Lavang' in field 2; in field 4, by contrast, the pH-cultivar interaction resembled that of the preceding year (Figure 3). Compaction more than halved the yields in field 4 and was clearly harmful also in fields 1 and 2. pH-compaction or compaction-cultivar interactions were generally not particularly marked.

Also in the compaction-cultivar experiment, seed yields of 'Lavang' diminished severely from the first to the second ley year (Table 4). A marked decline was observed even for 'NLH 3' and 'Ryss', yet, the former maintained the leading position in 1990. On average for cultivars, the depression in the second year was more marked on the light than on the heavy soil, but contrary to the results from the previous year, compaction seemed to have little impact on seed yields in 1990 (Table 3), and no clearcut compaction cultivar interaction could be recorded.

Third ley year

Because of invasion of other grasses, fields 1 and 3 were not harvested in the third ley year, and even in field 4, yields were rather poor (Table 2). Whereas the yield suppression by compaction was similar to that of the previous year, low pH values did not appear to be as detrimental as in 1989, particularly not in field 4. As in the first ley year, significant pH-compaction interactions indicated that the optimum pH level was higher in loose than in dense soils (Figure 4). In

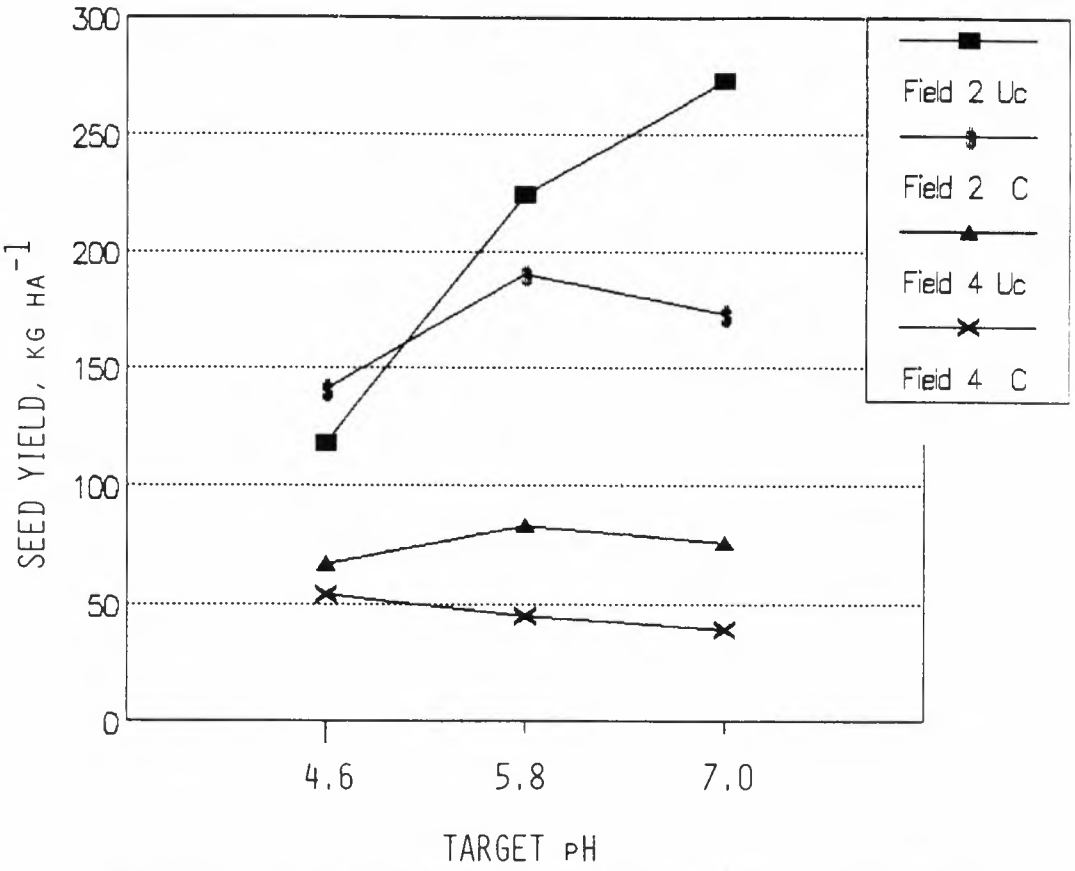

Figure 4. Seed yields (100% purity; 14% water content) of smooth meadow grass in the third ley year (1990) as influenced by soil pH on compacted (C.) and uncompacted (Uc.) subplots in fields 2 and 4 (silt loams)

field 2, 'Leikra' actually gave a better yield than in any of the preceding years, and 'Lavang' improved slightly compared with the poor results in 1989.

Yield components

Simple correlation analyses on the yield component data for 'Leikra' and 'Lavang' presented in Table 5 revealed that panicle number and seed number per panicle were significantly related to seed yield in both cultivars (Table 6). While seed number per panicle was the component most strongly correlated with yield in 'Leikra', panicle number exerted the greatest influence in 'Lavang'. Thousand seed weight showed little variation between treatments and was in fact negatively related to seed yield in the latter cultivar. Negative relationships also existed between panicle number on the one hand and the components constituting seed yield per panicle on the other. For 'NLH 3', 'Ryss' and the breeding populations, data were considered to be too limited to perform separate analyses. However, in a multiple regression comprising all six cultivars, panicle number accounted for 39% of the yield variation. Stepwise inclusion of seed number per panicle and thousand seed weight raised the coefficient of determination to 65 and 71%, respectively.

A considerable variation existed among fields as to the impact of pH and compaction on the relative importance of

Table 5. Means, coefficients of variation and ranges of seed yield and measured (panicle number; thousand seed weight) and calculated (seeds per panicle) yield components in the smooth meadow grass cultivars 'Leikra' and 'Lavang'

	n	Mean	CV %	Range
		Leikra		
Seed yield (kg ha^{-1})	270	173	69	6-656
Panicle number (m^{-2})	270	632	54	42-2319
Seeds per panicle	270	130	84	11-808
Thousand seed weight (mg)	69	248	12	72-301
		Lavang		
Seed yield (kg ha^{-1})	272	200	82	3-805
Panicle number (m^{-2})	272	819	77	14-3183
Seeds per panicle	272	103	71	18-630
Thousand seed weight (mg)	69	285	11	169-337

Table 6. Simple correlation matrices among seed yield (SY) and the components panicle number (PN), seed number per panicle (SN) and thousand seed weight (TSW) in the smooth meadow grass cultivars 'Leikra' (n = 270) and 'Lavang' (n = 272)

	'Leikra'			'Lavang'		
	PN	SN	TSW	PN	SN	TSW
SY	0.37***	0.51***	0.24***	0.75***	0.25***	-0.30***
PN		-0.34***	-0.22***		-0.24***	-0.36***
SN			0.23***			-0.002ns

panicle number and seed number per panicle, and it was hardly possible to speak of a common trend. On the other hand, the overall analysis revealed that thousand seed weight (mg) tended to decrease with pH elevation:

	Target pH			
Year	4.6	5.8	7.0	Sign.
1988	253	240	239	ns (P = 0.09)
1989	283	273	274	ns (P = 0.14)
1990	283	275	263	ns (P = 0.27)

In fields 5 and 6 great differences were noted among cultivars in seed yield composition (Table 7). With the exception of 'KvEr 25/24', a drop in panicle number was clearly observed from the first to the second ley year. The decline was most severe in 'Lavang' and 'Ryss', in turn 39 and 38%, but for the latter cultivar this was partly compensated by an increase in seed number per panicle. On average for treatments, thousand seed weight was 8% lower in 1990 than in 1989, but the relative difference between cultivars was almost the same, 'Ryss' ranking first in both years. 'Leikra' was generally inferior in panicle number and seed weight, but had the second highest and highest seed number per panicle in 1989 and 1990, respectively. The high seed yield in 'NLH 3' could mainly be ascribed to the many seeds per panicle; panicle number was in fact somewhat lower than in 'Ryss' and the breeding materials from Kvithamar.

Straw yield

Because of invasion of other grasses and different harvesting methods, the most reliable estimates of straw yield were obtained at Hellerud (Table 8). While pH elevation generally had a positive influ-

Table 7. Panicle number (PN m^{-2}), seed number per panicle (SN) and thousand seed weight (TSW mg) of six cultivars of smooth meadow grass in the first and second ley years. Means of uncompacted and compacted plots in fields 5 and 6

	Leikra	Lavang	NLH 3	Ryss	KvEr 2/21	KvEr 25/24	Sign.	$LSD_{0.05}$
				First ley year (1989)				
PN	939	1357	1208	2041	1556	1380	ns	-
SN	184	139	206	64	99	124	*	64
TSW	284	301	330	490	326	369	***	32
				Second ley year (1990)				
PN	732	827	977	1265	1141	1556	ns	-
SN	193	120	180	97	117	86	*	72
TSW	275	305	319	412	305	322	***	12

Table 8. Main effects of pH, compaction (Uc./C.) and cultivar on straw yields (kg ha^{-1}) of smooth meadow grass in the first (1988), second (1989) and third (1990) ley years on a silt loam (field 4)

	Target pH										
	4.6	5.8	7.0	Sign.	$LSD_{0.05}$	Uc.	C.	Sign.	Leikra	Lavang	Sign.
1988	2660	4060	4140	**	870	3080	4150	***	4110	3130	***
1989	3840	4610	5760	***	550	5390	4080	***	6070	3410	***
1990	3270	3580	3830	ns	-	3930	3190	**	4680	2450	***

ence on this character, compaction seemed to be favourable in the first ley year, but harmful in 1989 and 1990. The superiority of 'Leikra' to 'Lavang' was greater in the second and third ley years than in the first ley year.

The impact of tractor traffic on straw yields in fields 5 and 6 was inconsistent and will not be reported here. On average for soil types, compaction treatments and ley years, 'NLH 3' had the highest and 'Lavang' the lowest dry matter production.

Lodging

In 'Lavang' lodging was negligible for all fields. In 'Leikra' lodging increased with pH in field 1 in the second ley year and in field 3 in both years (Figure 5). In field 4 an insignificant decrease was recorded as pH surpassed 5.8 in 1988 and 1989, but not in 1990. In two of the second and in one of the third-year stands of 'Leikra', lodging percentages were higher on uncompacted than on compacted plots:

	Uncompacted	Compacted
Field 1 (second ley year)	23	8
Field 4 (second ley year)	30	7
Field 4 (third ley year)	16	4

In the compaction-cultivar experiment, stands of 'Lavang', 'Ryss', 'KvEr 2/21' and 'KvEr 25/24' were usually erect until harvest. On average for fields 5 and 6, lodging in 'Leikra' was assessed as 41% in 1989 and 82% in 1990. For 'NLH 3' the corresponding figures were 66 and 60%.

Germination

In the pH-compaction-cultivar experiment, no overall effect of pH or compaction on germination could be detected in the first and third ley years. In the second ley year germination after 10 as well as after 28 days was significantly higher in uncompacted than in compacted plots, and there was a tendency ($P=0.21$) for pH elevation to improve germination capacity (Table 9). 'Lavang' generally germinated 5-10 percentage units better than 'Leikra', the difference

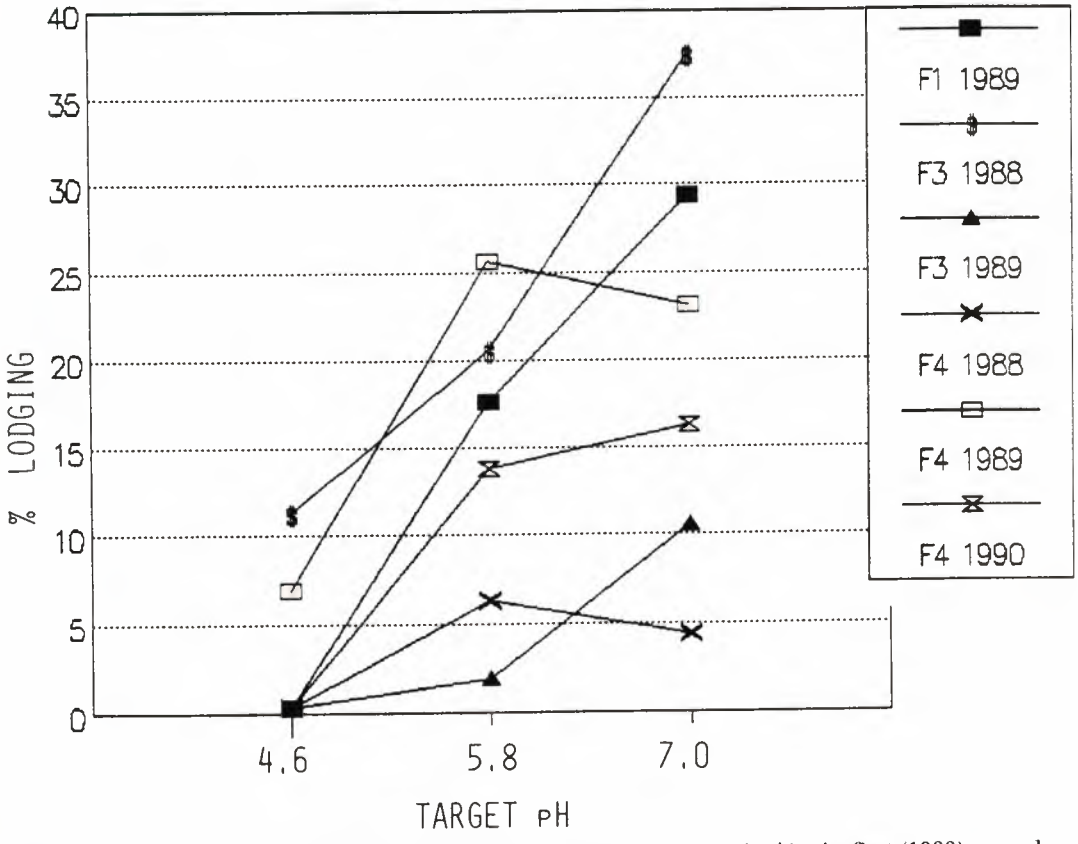

Figure 5. Percent lodging at harvest of the smooth meadow grass cv. 'Leikra' in the first (1988), second (1989) and third (1990) ley years as influenced by soil pH in fields 1 (F1), 3 (F3) and 4 (F4)

being greater after 10 than after 28 days. Also in fields 5 and 6 a greater variation was recorded among cultivars for germination after 10 compared with after 28 days (Table 10). 'Lavang' and 'Ryss' again germinated rapidly and uniformly, whereas 'Leikra' exhibited the lowest germination capacity, notably in 1989. For the material as a whole, the correlation coefficient r = 0.71*** was calculated between speed of germination and germination capacity in 'Lavang'; for 'Leikra' the corresponding figure was r = 0.51***.

Table 9. Germination capacity of seeds from the second ley year (1989) as affected by soil pH and compaction. Means of two cultivars and four experimental fields

	4.6	5.8	7.0	Mean *
Uncomp.	79.0	82.3	83.8	81.7
Comp.	76.3	77.2	80.9	78.1
Mean ns (P=0.21)	77.6	79.7	82.4	
Interaction : ns				

Weed contamination

Some invasion of *Poa annua* and *Alopecurus geniculatus* occurred in all the experimental fields. In the pH-compaction-cultivar series *P. annua* was especially a problem in fields 3 and 4, the average content in cleaned seed from the first ley year being as high as 23.0 and 34.2%, respectively. The contamination was remarkably lower in 1989; in turn 2.0 and

Table 10. Speed of germination (SG) and germination capacity (GC) for six cultivars of smooth meadow grass. Means of compacted and uncompacted plots in experimental fields 5 and 6; first and second ley years

	Leikra	Lavang	NLH 3	Ryss	KvEr 2/21	KvEr 25/24	Sign.	$LSD_{0.05}$
				First ley year (1989)				
SG	50.4	77.0	47.5	69.8	63.0	55.8	**	12.0
GC	77.0	88.1	82.5	88.0	86.4	80.3	**	4.9
				Second ley year (1990)				
SG	76.1	80.9	73.5	84.1	81.1	75.1	*	5.7
GC	88.1	88.8	94.3	92.0	88.5	89.2	**	1.9

1.7%, and the percentage fell even further in the third ley year, when only 0.04% of *P. annua* was detected in seed from field 4. *A. geniculatus* created the greatest problem in field 2, the average content being 5.4, 17.7 and 5.3% in the first, second and third ley years. No significant treatment difference was recorded as to weed contamination; nevertheless, for *A. geniculatus* there was a tendency towards its being most widespread on acid and uncompacted plots where the establishment of smooth meadow grass was incomplete. On average for fields, treatments and ley years, seed lots of 'Lavang' contained 7.2% *P. annua* and 5.4% *A. geniculatus* the corresponding percentages for 'Leikra' being 5.1 and 3.0, respectively.

In the compaction-cultivar experiment, invasion of *P. annua* was more severe on compacted than on uncompacted plots (Table 11). Whereas seeds of 'NLH 3' and 'Leikra' were significantly purer than seeds of 'Lavang' and 'Ryss' in the first ley year, only the lots of 'Lavang' remained heavily contaminated in 1990. For *A. geniculatus* no difference was detected between cultivars or compaction treatments.

DISCUSSION

Plant establishment

Contrary to common practice farther south in Europe, Norwegian seed stands of smooth meadow grass are usually seeded without a cover crop in order to guarantee a reasonable panicle production in the first ley year (Jonassen & Hillestad 1990). This method of establishment is not without problems, however. The seeds of smooth meadow grass are small and slow to germinate, and a uniform and rapid emergence is very dependent on sowing depth, soil temperature and water availability (Youngberg 1981, Nordestgaard 1983c). If conditions are not appropriate, weeds like *Poa annua* and *Alopecurus geniculatus* are likely to predominate, and this often leads to rejection of seed fields (Hagsand 1983, Synnes 1984).

In the present investigation acidification of the soil by sulphuric acid generally resulted in lower scores for plant establishment (Table 1). The effect was less pronounced in field 2, where a pH value of 4.8 was measured in July 1987, than in fields 1, 3 and 4, where the corresponding pH was 4.3, 4.4 and 4.5, respectively (Aamlid 1990d). In field 3 in particular, where the highest amounts of sulphuric acid had been applied, large spots of the most acid plots remained almost without vegetation during the whole experimental period. Although such acid soils might have little relevance to practical seed production, soil reaction values below 5 are not exceptional in the poorly buffered growth media on many athletics fields, especially in the southernmost part of Norway where acid

rain adds to the acidifying effect of ammonia fertilizers (Håbjørg 1977). Under such conditions, not only growth, but also germination of smooth meadow grass will be impaired.

Apart from field 3, the results presented in Table 1 strongly support the practical experience that a good establishment of smooth meadow grass is more complicated on heavy than on light soils. Although all fields were rolled with a Cambridge roller before seeding, seeds were obviously placed too deeply into the soil on the uncompacted plots of fields 2 and 4 in 1987, and germination was therefore seriously hampered. For that year, rainfall in June was 38% and 123% above normal at Kjevik (close to Landvik) and Gardermoen (close to Leirsund/Hellerud), respectively, whilst the mean temperatures were 2.3 and 2.5°C below the monthly average. The wet and cold weather clearly favoured shallow seeding and thus the establishment on compacted plots. In 1988, care was taken to prevent too much soil from covering the seeds, but, ironically enough, germination failed completely after compaction in field 7 and was generally better on untrafficked than on trafficked plots in fields 5 and 6. In this year, the mean temperatures for June were 3.0 and 4.0°C above normal at Kjevik and Gardermoen, respectively, and rainfall was rather sparse at both locations.

From experiments with many species, it is well documented that low seed rates are often advantageous in grass seed production (Nordestgaard 1975a, 1975b, 1979, Jonassen 1980). Preliminary results with fodder types of smooth meadow grass also suggest that seed rates of 2.5 kg ha^{-1} give higher yields than 5 or 10 kg ha^{-1} (Aamlid unpublished), and this will probably be even more so for turf types. However, particularly for heavy soils, a general recommendation of such low - or even lower - seed rates would require more adequate sowing depths than were achieved in the present experiment. The optimal firmness of the seedbed certainly depends on seeding equipment and moisture conditions and can hardly be related to any particular bulk density or penetration resistance.

Yields

The effects of pH on seed and straw yields (Tables 2 and 8) are in general agreement with those reported for single plants (Aamlid 1990b) and can mainly be attributed to aluminium toxicity at soil reaction values below 5.0 (Foy 1974, Marschner 1986), and to stimulation of nitrogen mineralization with rising pH beyond this value (Curtin & Smillie 1986, Haynes & Swift 1989). The latter effect also explains why the first year seed yields on compacted plots in fields 2 and 4 declined as pH surpassed 5.8 (Figure 1): On these well-established plots nitrogen mineralization probably became too plentiful during the wet summer and autumn of 1987 (rainfall for June-October 44% and 48% above normal at Kjevik and Gardermoen, respectively), and stands, especially of 'Lavang', appeared rather dense at the end of the growth period. A major proportion of the late-formed tillers in this cultivar had probably not passed the juvenile stage in autumn or - alternatively - had succumbed to the competition for light, nutrients and water in the following spring. These results are consistent with Dutch (Meijer 1984, Meijer & Vreeke 1988) and Danish (Nordestgaard 1987) studies, in which an inverse relationship between tiller density in autumn and panicle production in summer has been documented.

Because stand density normally imposes stronger restrictions to seed yield in old as opposed to young leys, it was thought that the positive effect of pH elevation would diminish with time. Some support for this hypothesis may be drawn from a comparison of the second and third year results, particularly for field 4 where both cultivars appeared rather vegetative and no response to pH could be recognized in 1990. Nevertheless, the

strong yield enhancement caused by liming in 1989 demonstrates that other factors have had some influence on the effect of pH on nitrogen mineralization and thereby stand density. Most important was probably the May-June precipitation, which was much lower in 1989 than in 1990, especially at Landvik (90 vs. 154 mm). In a fertilization-growth regulation experiment adjacent to field 2, seed yields of 'Leikra' increased by 41% in the first ley year (1988), by 72% in the second year and by a mere 16% in the third year when nitrogen inputs were increased from 30 to 90 kg ha^{-1}. This indicates that the impact of pH in the present experiment was primarily an effect of nitrogen, and that the optimal nitrogen inputs or pH value will be lower in wet than in dry years. Negative liming-nitrogen interactions have indeed been reported from seed production experiments with smooth meadow grass (Rampton et al. 1971).

Both nitrogen quantities and the time of application in autumn and spring are very central factors in the achieving of high grass seed yields (Larsen & Nordestgaard 1969, Nordestgaard 1976, Nordestgaard 1983a). The uncontrolled nitrogen mineralization associated with liming beyond 5.8-6.0 is therefore undesirable and may lead to lodging and many vegetative tillers, notably in wet years. In recent Danish experiments, seed yields of meadow fescue (*Festuca pratensis* Huds.) and perennial ryegrass (*Lolium perenne* L.) have been insignificantly higher at pH 6.3 than at pH 7.0. (Nordestgaard, pers. comm.). In the great seed production district of Oregon, USA, the following pH (H_2O) values are considered optimal for various grass species: Colonial bentgrass (*Agrostis capillaris* L.): 5.3; red fescue (*Festuca rubra* L.) and perennial ryegrass: 5.5; smooth meadow grass and cocksfoot (*Dactylis glomerata* L.): 5.8 (Youngberg 1980).

Despite tractor traffic being more harmful to plant establishment on the silt loam (field 6) than on the sandy loam (field 5) in 1988, the first year seed yields were strongly increased by compaction in field 6 whilst the opposite occurred in field 5 (Table 3). This result substantiates the conclusion from single plant studies in which compaction was shown to be harmful on light but beneficial on heavy soils (Aamlid 1990c). The growth enhancement by compaction in field 6 can possibly be explained by a better root-soil contact (de Willigen 1984) or an increase in the unsaturated hydraulic conductivity (Håkansson et al. 1988). On the other hand, mechanical impedance is the most likely explanation for yield reduction in field 5, as the average penetration resistance on compacted plots was as high as 3.11 MPa (Aamlid 1990d), which is beyond most of the limits reported to inhibit root proliferation (Greacen et al. 1969).

Since a higher proportion of the seed yield will usually be produced on tillers from rhizomes in the second than in the first ley year, it was surprising that the harmful effect of compaction in field 5 was negated in 1990. Again, this may be interpreted as a result of a too abundant nitrogen supply causing many secondary vegetative tillers on uncompacted plots in this rather wet season. Unfortunately, no analysis of soil nitrogen was conducted on fields 5 and 6, but samples taken from fields 2 and 4 in August 1989 revealed that the nitrate content was 47-65% higher on uncompacted than on compacted plots, even after a long dry period (Aamlid 1990d). This is in good agreement with Njøs (1978) who found that soil nitrification was restrained by tractor traffic.

The cultivar 'Lavang' originates from a 69° northern latitude and most likely belongs to the subspecies *P. pratensis alpigena* which prevails in arctic environments (Åkerberg & Nygren 1959). It has a rather decumbent growth habit, especially at short photoperiods (Aamlid 1990a). In the pH-compaction-cultivar experiment at Landvik it gave more than twice as high a seed yield as 'Leikra' in

the first ley year (1988), but thereafter regrowth was very poor, and plots never regained a healthy, green appearance until winter. At Hellerud (field 4) plants resumed growth much faster and tillering during August and September was in fact more profuse in 'Lavang' than in 'Leikra'. Moreover, the mean temperature for the period November 1988-March 1989 was 4.2° at Landvik (Kjevik) as opposed to -1.2°C at Hellerud (Gardermoen); this must have led to much higher respiration rates and concomitant carbohydrate depletion in the faded, non-assimilating plants of 'Lavang' at the former location. Exactly the same situation recurred one year later in the compaction-cultivar experiment at Landvik; the winter 1989-90 was also exceptionally mild (mean temperature November-March 4.0°C at Kjevik), and seed yields of 'Lavang' were nearly halved from the first to the second ley year. These findings are consistent with earlier trials on seed production of various cultivars of smooth meadow grass at different locations in Norway (Håbjørg 1979) and throughout the Nordic countries (Nord estgaard 1983b). Håbjørg (l.c.) in fact suggested that arctic cultivars would produce a good seed crop every second year when grown at southern latitudes; to some extent, the results from field 2 may be interpreted as favourable to this theory. It remains to be elucidated whether the tendency can be counteracted by nitrogen application and - if necessary - irrigation immediately after seed harvest.

Yield components

The value of the yield component analysis presented in this report is entirely dependent on the reliability of the panicle countings in the field. For example, it seems rather unrealistic that a panicle of smooth meadow grass could carry as many as 808 seeds, as reported for 'Leikra' in Table 5; this must certainly be an artefact arising from underestimation of panicle number on the actual plot. To a certain degree the negative relationship between panicle number and seed number per panicle (Table 6) may also be mediated by such irregularities; on the other hand, it seems quite reasonable that the reduction in average size of inflorescences in dense stands is due to competition. This is confirmed by single plant studies in which seed numbers per panicle were generally higher than in the present investigation (Aamlid 1990b, 1990c). From work with perennial ryegrass, Hampton & Hebblethwaite (1982) suggested that there would be a shift in importance of the different yield components in favour of seeds per spike as number of fertile tillers reached 2000 per m^2. Later they documented that seed number per m^2 - and hence seed yield - was closely related to fertile tiller number in non-lodged crops only (Hampton & Hebblethwaite 1983). This is compatible with the present finding that seed number per panicle had a greater impact on seed yield in the lodging-susceptible cultivar 'Leikra' than in 'Lavang' (Table 6). Nevertheless, at the rather low yield levels prevailing in Norwegian smooth meadow grass seed production, there is little doubt that panicle number is the most essential yield component. This is also the case in Denmark, where it is roughly considered that panicle number accounts for 70% of the seed yield variation (S. Andersen pers. comm.).

Apart from the highly significant differences between cultivars, thousand seed weight showed little variation as compared with the other yield components (Table 5). This supports the general experience that most grass species maintain a relatively constant seed weight over a great range of environmental conditions (Hampton & Hebblethwaite 1983, Marshall 1985). It might, however, be assumed that the cleaning and standard blowing procedures routinely applied to seed lots remove some of the biological variation in this character. The reduction in seed weight mediated by pH elevation is compatible with a similar effect of in-

creased nitrogen application in cocksfoot (Moen 1982).

Germination

The negative effects of compaction and low pH values on germination characteristics in 1989 are hard to explain, unless caused by rough threshing as a result of small straw yields. On the other hand, the superiority of 'Lavang' to 'Leikra' as regards speed of germination and germination capacity is in good agreement with official Norwegian seed statistics (Statens frøkontroll 1989) and with earlier studies (Aamlid 1990c). Although the seed rate in seed production experiments is normally corrected for germination capacity, great differences in speed of germination might have a significant impact on plant establishment at low temperatures and adverse soil conditions (Charlton & Hampton 1989).

Weeds

Although weeds like *Poa annua* and *Alopecurus geniculatus* are disastrous in smooth meadow grass seed production primarily because seeds cannot be separated by cleaning, the heavy infestation of these grasses on some fields in the present investigation certainly depressed seed yields severely as well. For example, Rolston & Hare (1986) calculated that a 1% increase in weed cover of *P. annua* resulted in a 7 kg ha^{-1} seed yield reduction in colonial bentgrass, cocksfoot and phalaris (*Phalaris aquatica* L.). Compared with barley (*Hordeum vulgare* L.) and timothy, smooth meadow grass is known to compete very poorly against *P. annua* (Netland 1985). It is, however, interesting to note the continued drop in contamination by this weed from the first to the second and third ley years and the difference in competitive ability of smooth meadow grass cultivars (Table 11). These observations indicate that *P. annua* is very susceptible to competition for light, and that infestation is primarily a problem in the first year seed crops of smooth meadow grass.

ACKNOWLEDGEMENTS

The author is indebted to the staff at Hellerud Experimental and Seed Multiplication Farm and Landvik Agricultural Research Station for excellent technical assistance and good cooperation. Rapid and precise seed purity analyses at the Norwegian State Seed Testing Station are also gratefully acknowledged. Thanks are particularly expressed to Professors A.O. Skjelvåg and B. Opsahl, R. Hillestad and Dr G.H. Jonassen for invaluable discussions and encouragement and to Professor A.O. Skjelvåg and P. Aamlid for correcting the English language.

Table 11. Contamination by *Poa annua* L. (weight %) in cleaned seed of four ecotypes of smooth meadow grass from the first (1989) and second (1990) ley years grown at two compaction treatments. Means of experimental fields 5 and 6

	1989			1990		
	Uncomp.	Comp.	Mean*** $LSD_{0.05}=2.0$	Uncomp.	Comp.	Mean (ns) (P=0.09)
Leikra	1.0	2.2	1.6	0.05	0.18	0.11
Lavang	2.2	10.2	6.2	0.88	5.23	3.05
NLH 3	0.4	2.3	1.3	0.01	0.04	0.03
Ryss	1.6	9.4	5.5	0.02	0.46	0.24
Mean	1.3	6.0		0.16	0.99	
	ns (P=0.06)			ns		
Interaction: ** ($LSD_{0.05}=4.2$)				ns		

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Norwegian Journal of Agricultural Sciences

Vol. 5 1991 No. 3

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