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

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Fillet gaping in farmed Atlantic salmon (*Salmo Salar*)

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An evaluation of fillet gaping was carried out at three factories processing farmed Atlantic salmon. In two of the factories 22-25% of the fillets were found to have moderate to severe gaping and it appeared that prolonged storage time on ice increased gaping. In two separate selections, 10 fillets with and 10 without gaping were compared. Resistance against depression as well as elasticity was reduced in fillets with gaping. Fillets without gaping showed a higher protein content, less glycogen and a lower level of pH, while no differences were observed in fat content. In the first selection the mean fat content was higher, and texture measurements (Instron) revealed a softer consistency than in fillets from the second selection. When the correlation between rough handling of fish before slaughter and gaping was further studied, it was found that fillets from roughly handled fish tended to have more gaping, but no differences were observed in texture measurements. Sensory analyses revealed stronger taste attributes in carefully treated fish.

Key words: Atlantic salmon, fat content, fish fillets, gaping, glycogen, Instron, pH, sensory analyses, texture.

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Quality classification of farmed salmonids is at present based mainly on external criteria such as loss of scales, colour of skin, wounds or dwarfing. A classification of this kind does not take into account the chemical composition and texture of the fish muscle and is of little value to the fish processing industry.

Gaping is a textural problem that is difficult to detect before filleting. Gaping occurs when the connective tissue in myocommata breaks and the muscle cells separate (Love 1988). Smoked fillets take on a poor appearance, displayed as light liquid spots in a vacuum-packed product. Removing the skin becomes difficult and sliced smoked fillets fall apart. Such fish will be unfit for use in several dishes and the buyers will not give a good

price for these products. More information about the processes leading to gaping in salmon fillets and the development of a classification system that can expose gaping and other textural problems in farmed salmonids are of great importance to the salmon processing industry.

Lavèty (1984) and Love (1988) have presented reviews of the gaping problem and it has been found that gaping generally shows seasonal variations and has a correlation with fillet pH and water content, worsened by freezing and thawing. Rough handling of the fish after slaughter may also increase gaping and there are marked differences between species. The problem has mainly been studied in wild fish, especially cod, but few studies have been reported dealing with farmed salmonids. Lavèty et al. (1988) made observations indicating differences between salmonids and cod; changes in pH, in particular, seem to be of less importance in relation to the gaping problem in salmonids. There is, however, not enough detailed knowledge about the processes leading to gaping of salmon fillets.

Workers in the fish processing industry are of the general opinion that rough handling of fish before slaughter increases gaping. There is, however, little information in the literature concerning such a connection.

To estimate the significance of the gaping problem we started this work by registering all cases of gaping in three processing factories. Furthermore, the chemical and physical differences between fillets with and without gaping were investigated. An experiment was also carried out to study relations between gaping and handling of salmon before slaughtering.

MATERIALS AND METHODS

Registration of gaping in salmon processing factories

The recording of gaping in salmon fillets was carried out in three different Norwegian processing factories. Factory 1, is situated in southeast Norway, while the other two factories (2 and 3) are located on an island on the west coast. Classification was carried out according to the scale presented in Table 1. The registration groups in the different factories can be seen in Table 2.

Table 1. Scale used to classify salmon fillets according to gaping severity

Score	Description
0	No gaping
1	Few small[1)] slits (less than 5)
2	Some small slits (less than 10)
3	Many slits (more than 10 small or a few large[2)])
4	Severe gaping (many large slits)
5	Extreme gaping (the fillet falls apart)

[1)] < 2 cm
[2)] > 2 cm

Table 2. Fish fillets evaluated in the registration of gaping in Factories 1, 2 and 3

Fish farm	Storage	Quality class	Weight (kg)	Number of fillets	Skin
Factory 1	Days on ice				
A	5	superior	3 - 4	223	no
B 1a	5	ordinar	3 - 4	390	no
B 1b	7	ordinar	3 - 4	421	no
B 2	5	ordinar	4 - 5	302	yes
B 3 a+b	4	superior	3 - 4	144	no
C	5	superior	5 - 6	73	yes
Factory 2	Weeks in freezer				
D	5	fish for prosessing	1 - 2	100	yes
Factory 3	Hours after slaughter				
E1	6[1)]	superior	2-3	112	yes
E2	6.5[2)]	superior	3-4	60	yes
E3	7[2)]	superior	2-3	128	yes

1) pre-rigor
2) in rigor

Factory 1

The first registration was carried out in Factory 1 where the production line started with a combined filleting and stick-salting machine. The fillets were then transferred manually from this machine to racks, which were then moved into the smoking oven. After smoking (cold smoking at 18-24°C) the fillets were vacuum packed. Two days' production was evaluated. The raw material was delivered by three farmers (A, B and C). The salmon were classified as superior or ordinary according to the Norwegian classification system and some fillets were evaluated with the skin on, others without skin. Three different deliveries and two different size classes from farm B were studied. Fish from one delivery from this farm (B1) were evaluated after 5 (B1a) or 7 (B1b) days on ice. The different groups (A, B1a, B1b, B2, B3a and C) were registered before smoking, when leaving the stick-salting machine, but one group (B3) were also evaluated after smoking (B3b).

Factory 2

In the second registration (Factory 2) 100 fillets made up from deep-frozen raw material were classified (D). The salmon, classified as fish for processing (1-2 kg) were frozen one day after slaughtering, stored for 5 weeks and thawed on ice before processing. Filleting was done by hand, and gaping studied without removing the skin.

Factory 3

The last registration was carried out in Factory 3, which had its own fish farm. The salmon (E) were all of superior quality (2-4 kg) and had been starved for three weeks. Filleting was carried out using a filleting machine on the same day as slaughtering. Gaping was evaluated directly after filleting. The skin was not removed. The fish were divided into three groups (E1, E2 and E3) depending on rigor development (Table 2).

Comparative studies of fillets with and without gaping

Twenty fillets, 10 with gaping (given scores 3 or 4 according to Table 1) and 10 without gaping were taken from the production line in Factory 1 in two separate selections for further examination. The fish in selection 1 had been stored for 4 days on ice, while the fish in selection 2 were stored for 6 days. The fillets were packed in plastic bags and stored at 4°C for 48 or 24 h, respectively, before further examination.

Texture measurements

Fillet texture attributes were measured with an Instron Universal Instrument model 1140 using a modification of a method described by Børresen (pers. com. 1990). The fillets were taken from the refrigerator and the plastic bags removed before placing the fillets on a metal plate. A plunger with diameter 20 mm and sharp edges was placed in a position barely touching the surface of the fillet. The plunger was then pressed downwards until it penetrated the surface of the fillet (yield point). The crossbar velocity was 100 mm/min. The resistance from the fish muscle was recorded as a depression curve. Three readings were made on the curve corresponding to 5 and 7.5 mm depression and the yield point. The yield point is regarded as expressing the toughness of the fillet (Ando et al. 1991), while the resistance against depression expresses hardness (Børresen 1986). A measure of elasticity (ΔF) was obtained by pressing the plunger about 5 mm down into the fillet in two consecutive measurements at the same point on the fillet. The reduction in compression force (ΔF) was calculated using the following formula $\Delta F = (1\text{-}F_2/F_1)100\%$, where F_1 represents the force in the first measurement and F_2 the force in the second measurement. A low ΔF indicates high elasticity. The compression resistance measurements were made on the front part of the fillet about 20 cm from the neck, elasticity about 30 cm from the neck, both on the dorsal side (Fig. 1a). As far as possible the measurements were carried out in areas with no visible gaping.

Chemical analysis

About 200 g fillet was sampled in front of the dorsal fin immediatly after the Instron measurements were completed, cleaned for visible fat, homogenized and wrapped in aluminium foil, and stored for three weeks at -35°C before examination. All chemical measurements, with the exception of pH, were performed in two replicates taken from the frozen homogenate.

pH was measured in two replicates after mixing 5 g unfrozen homogenized fish muscle with 10 ml distilled water at 20°C.

Fillet fat content was measured using the SBR-ether extraction method (Schmid-Bondzynski-Ratslaff) for determination of fat content in meat and meat products described by the "Nordic Committee on Food Analysis" (1974).

Nitrogen was determined using the Macro-Kjeldahl method described by the Official Methods of Analysis of the Association of Official Analytical Chemists (1970). A factor of 6.25 was used to estimate the protein content.

Solids were determined by calculating the loss of weight after drying 2 g homogenized fish muscle at 104°C for 24 h.

Glycogen was measured using a modification of the method described by Dalrymple & Hamm (1973). Fish muscle was homogenized with perchloric acid. Amyloseglucosidase was added to convert glycogen to glucose, pH was adjusted to 4.8 with 5.4 M KOH or 3 N $HClO_4$. The sample was centrifuged and the glucose content of the supernatant determined using an Encore System II analyser and BECKMAN Dri-STAT reagents for glucose.

Handling before slaughter, and gaping

Slaughtering procedures

Thirty salmon (*Salmo salar*) were slaughtered at the sea station of the Institute of Aquaculture Research (AKVAFORSK) at Averøy in Norway. The fish had been fed a commercial pelleted dry feed and were starved for 14 days before slaughtering. The mean weight and length were 3.05 kg ($\pm$0.41) and 66.5 cm ($\pm$3.3), respectively. Fifteen fish were caught as carefully as possible with a landing net and bled immediately afterwards. Rough handling of the remaining 15 fish, was achieved by shrinking the net pen 1.5 h before slaughtering. All the fish were later given the same treatment, and gutted following Norwegian standards. A piece of muscle was taken from the neck within a few minutes of slaughtering, wrapped in aluminium foil and immediately frozen for later measurement of pre-rigor glycogen.

Registration of gaping

Twenty fish, 10 carefully and 10 roughly handled (mean weights 3.26 kg $\pm$0.27 and 3.24 kg $\pm$0.31, respectively), were transported to Factory 1 and stored on ice for 4 days before filleting and cold-smoking. Gaping was evaluated after filleting and stick-salting, before smoking.

pH, texture, colour and sensory analysis

The remaining five fish from each treatment (mean weights 2.62 kg $\pm$0.29 and 2.62 kg $\pm$0.16) were stored on ice for 4 days before measuring for pH, texture and colour. Samples for sensory assessment were frozen at the same time, pending analysis. Figure 1b shows which part of the fish the samples were taken from for the different analyses.

Measurements of pH and compression tests were performed according to previous descriptions, but elasticity was not measured.

Colour was measured with a Minolta Chroma Meter using a measuring cell with a diameter of 2.5 cm. A sample fitting the cell was taken from the dorsal muscle about 20 cm from the neck. Three measurements were carried out on one sample by turning the measuring cell 90° between each measurement (No & Storebakken 1991).

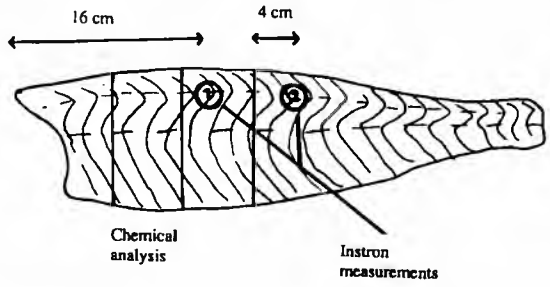

Fig. 1a. Samples analysed in the comparative studies of fillets with and without gaping

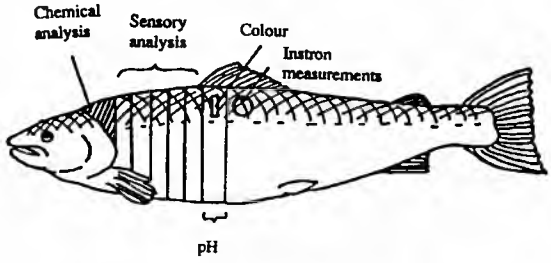

Fig. 1b. Samples analysed in the handling experiment

Five assessors participated in the sensory test and were chosen from among employers and students at the Department of Food Industries. The fish were cut into cutlets, packed in plastic bags, frozen and stored at -35°C for 3 weeks. Before assessment the fish were thawed at room temperature (22°C) for 4 h, wrapped in aluminium foil and stored at 4°C until the following day. The cutlets were cooked in aluminium foil in an oven at 200°C for 20 min. The assessment included colour (redness), juiciness, salmon taste, fish oil taste, rancidity and the total taste impression. The assessors were served two fish samples, A and B, at the same time; one from each group. Scores on a scale from -3 to +3 were given for each attribute, a positive score indicating that fish A had a stronger attribute than B. Pairs given score 0 showed no differences. Every assessor tasted a total of 25 pairs of fish during five sittings. Five pairs of fish still wrapped in aluminium foil were assessed at each sitting and served randomly.

Statistics

Chi-square test was used to test differences in gaping score frequencies between fillets that were registered in the three factories. A Student's t-test was used to test differences between fillets with and without gaping and between differently treated fish. F-test; a two-factor design was used in the comparative studies. Correlation analyses were used to

evaluate relationships between different measurements. The zero hypothesis was rejected at a level of 5%.

RESULTS

Registration of gaping in processing factories

The percentage distribution of gaping scores obtained in the registration is outlined in Table 3. Large variations were observed both between and within factories. While very little gaping was observed in Factory 3 (groups E1, E2, E3) significant gaping problems were revealed in Factory 1 (groups A, B1, B2, B3, C) and Factory 2 (group D), with an average of 25% of the fillets allotted gaping scores of 3 and 4. None of the fillets were given score 5. In Factory 2 25% of the fillets (group D) were given scores 3 and 4, compared with only 2.4% of the fillets in Factory 3 (group E). In this factory as much as 93.2 % of the fillets showed no gaping at all. Within Factory 1 variations in gaping severity, ranging from 10 to 40% of the raw fillets given scores 3 and 4, were observed between deliveries. Two groups (B2, C) of fish from Factory 1 were inskinned. In these groups 9.3% and 12.3% were given scores 3 and 4. In the groups without skin 16.2 - 39.6% of the fillets were given scores 3 and 4. It was found that a longer storage time on ice in fish delivered from farm B1 (groups B1a and B1b) increased the gaping score ($p < 0.05$).

Table 3. Registration of gaping in processing factories. Distribution of fillets in gaping score categories

	Gaping scores %						
Group	0	1	2	3	4	5	Mean score (±SD)
Factory 1							
A	22.0	23.3	29.6	21.5	3.6	0	1.55 (±1.70)
B1a	32.1	26.9	24.9	13.1	3.1	0	1.28 (±1.16)
B1b	17.9	19.5	30.6	26.2	5.8	0	1.83 (±1.18)
B2	40.7	30.1	19.9	8.3	1.0	0	0.99 (±1:03)
B3a	17.4	18.1	25.0	25.0	14.6	0	2.01 (±1.32)
B3b	4.2	11.1	29.9	30.6	24.3	0	2.59 (±1.10)
C	57.5	23.3	6.9	11.0	1.4	0	0.76 (±1.32)
Factory 2							
D	14.0	33.0	28.0	20.0	5.0	0	1.69 (±1.08)
Factory 3							
E1	99.1	0.0	0.0	0.9	0.0	0	0.03 (± 0.28)
E2	100.0	0.0	0.0	0.0	0.0	0	0
E3	80.5	5.5	7.8	3.1	3.1	0	0.43 (±0.99)

Comparative studies of fillets with and without gaping

Chemical composition

No differences were observed between fillets with and without gaping within each selection for fat or solids (Table 4). Selection 1 had the highest average solids and fat content. Protein content was higher in fillets without gaping in selection 1, but not in selection 2. Fillets in selection 2 had the highest average protein content. The glycogen levels found in the fillets were very low in both selections, but fillets with gaping had more glycogen than fillets without gaping in selection 2, and the same tendency was observed in selection 1. Only slight differences in pH were observed between fish with and without gaping. In selection 1, however, this difference was still significant; the fillets with gaping having the highest pH.

Table 4. Chemical composition (%ww) of fillets with and without gaping in two separate selections [1]

	Selection 1		Selection 2	
	Gaping (n=10)	No gaping (n=10)	Gaping (n=10)	No gaping (n=10)
Fat %	15.30[a2] (±2.08)	15.36[a] (±1.69)	12.60[b] (±1.25)	12.11[b] (±1.25)
Protein %	18.00[a] (±0.56)	18.60[b] (±0.48)	19.00[c] (±0.66)	19.10[c] (±0.26)
Solids %	35.00[a] (±1.32)	35.20[a] (±1.81)	33.30[b] (±1.24)	32.90[b] (±1.13)
Glycogen %	0.060[a] (±0.011)	0.051[a] (±0.010)	0.060[a] (±0.012)	0.044[b] (±0.014)
pH	6.28[a] (±0.03)	6.23[b] (±0.04)	6.28[a] (±0.04)	6.28[a] (±0.03)

1) Selection 1 stored on ice for 4 days, selection 2 stored on ice for 6 days

2) a, b, c, d indicate significant difference at 5% within one row.

Texture measurements

In both selections fillets with gaping showed less resistance against compression and lower yield point than fillets without gaping (Table 5). Statistically significant differences were observed at 7.5 mm compression in selection 2 and in yield point in both selections. In addition, a difference between the selections was found, fillets in selection 1 showing less resistance against depression.

In Table 6 it is shown that elasticity was higher in fillets without gaping than in fillets with gaping. The force needed to press down the plunger tended to be less in fillets with gaping, but the difference was not statistically significant. This is in accordance with the results recorded in Table 5 where no significant differences were found in the 5 mm compression point within each selection. Elasticity was only measured in selection 2.

Table 5. Depression measurement in fillets with and without gaping, measured in two separate selections [1]

Depression force (N)	Selection 1		Selection 2	
	Gaping (n=10)	No gaping (n=10)	Gaping (n=10)	No gaping (n=10)
5 mm	2.4[a2] (±0.8)	3.1[a,b] (±2.9)	3.3[b] (±1.1)	4.1[b] (±0.9)
7.5 mm	5.8[a] (±1.2)	7.8[a] (±2.7)	7.4[a] (±2.3)	9.8[b] (±1.4)
Yield point	8.6[a] (±2.3)	14.2[b] (±2.9)	11.2[c] (±4.2)	16.0[d] (±2.3)

1) Selection 1 stored on ice for 4 days, selection 2 stored on ice for 6 days
2) a, b, c, d indicate significant difference at 5% within one row

Table 6. Elasticity in fillets of salmon with and without gaping, selection 2 (stored on ice for 6 days)

Parameter	Gaping (n=10)	No gaping (n=10)
1. Depression (N)	4.9[a 1] (±1.9)	5.0[a] (±1.8)
2. Depression (N)	4.1[a] (±1.5)	4.3[a] (±1.4)
ΔF (% reduction)	16.8[a] (±3.1)	14.3[b] (±2.1)

1) a, b indicate significant difference at 5% within one row

Handling before slaughter, and gaping

Registration of gaping

A score of 3 or 4 was allotted to 50% of the fillets from roughly handled fish while only 35% of the carefully treated fish were given these scores (Table 7). Average scores were 2.45 (±1.15) and 2.00 (±1.26), respectively.

Table 7. Effect of handling before slaughter on gaping in salmon. Percentage distribution of gaping scores

Group	Gaping score %						Mean score (±SD)
	0	1	2	3	4	5	
Rough (n=10)	10	30	25	20	15	0	2.00 (±1.26)
Careful (n=10)	5	15	30	30	20	0	2.45 (±1.15)

Chemical and texture measurements

The results from texture, colour, pH and glycogen measurements are presented in Table 8. A tendency towards a higher pre-rigor glycogen content in the carefully treated fish and a negative correlation between pH post-rigor and glycogen pre-rigor ($r=-0.664$, $p<0.05$) was observed. These fish also seemed to give somewhat higher values for lightness, redness and yellowness. None of these differences were statistically significant, however.

Table 8. Effect of handling before slaughter on texture, colour and chemical composition of salmon

	Careful (n=5)	Rough (n=5)
Force at 7.5 mm depression (N)	10.22 (±0.83)	10.57 (±1.84)
Force at yield point (N)	15.39 (±0.83)	15.71 (±1.35)
L* (lightness)	38.21 (±0.34)	36.43 (±2.20)
a* (redness)	7.06 (±0.97)	6.67 (±0.79)
b* (yellowness)	9.82 (±0.83)	9.41 (±0.88)
glycogen (%) pre-rigor (n=15)	0.072 (±0.072)	0.065 (±0,018)
Post-rigor pH	6.20 (±0.04)	6.26 (±0,05)

Sensory analysis

The results of the sensory test are presented in Table 9. Both salmon taste and total taste impression were different between the groups and strongest in the fish treated carefully before slaughter. Juiciness and colour were not significantly different. However, the average of these variables was negative and this perhaps indicate that the roughly handled fish tended to have the strongest attribute. No differences were observed in oil taste or rancid taste.

Table 9. Sensory assessment of roughly and carefully handled fish[1)]

	Difference
Juiciness	-0.25
Salmon taste	+0.68*[2)]
Fish oil taste	0
Rancidity	0
Total taste impression	+0.63*
Colour	-0.12

1) Mean values (n=5) close to zero expresses small differences between groups. When the carefully handled fish had the strongest attribute the average is represented by a positive number

2) Indicates significant difference at 5%

DISCUSSION

Registration of gaping

The results of the survey revealed large variations in the gaping problem between factories. While hardly any fillets with gaping were observed in the factory that processed its own salmon shortly after slaughter, roughly one-quarter of the fillets in the factories processing frozen-stored or iced-stored salmon had high gaping scores. With this amount of gaping, the management of Factory 1 predicted an economic loss of 5-10%. In extreme cases such products were sold at a loss of 30-40%. Gaping is therefore a serious economic problem for this factory.

The high occurrence of gaping in fish from Factory 2 may be due to the fact that these fish were frozen one day after slaughtering, probably still in rigor. Furthermore, the fish were smaller than those in Factories 1 and 3. According to Love (1988) these factors will influence gaping. Freezing increases gaping, especially when the fish has entered rigor (Love et al. 1969; Love & Haq 1970), and small fish usually gape more than larger fish (Love et al. 1972).

The registrations indicated a higher incidence of gaping in fillets without skin, which indicates that removing the skin may increase the gaping problem. The skin probably affords some protection against gaping by supporting the structure of the muscles. Furthermore, the process of skin removal itself involves fairly rough handling of the fillet. El-Sherbieny (1973) reports that rough handling of cod (*Gadus morhua* L) in rigor increases the gaping and produces a very bad texture.

Smoked fish were evaluated as having significantly more gaping than unsmoked fish. Love (1985) and Lavèty (1984) suggest that high temperatures at the beginning of the smoking process may weaken the connective tissue and cause gaping. Ofstad et al. (1993) studied heat-induced liquid loss and structural changes due to heating (5 - 70°C) in muscle from cod (*Gadus morhua* L) and salmon (*Salmo salar*). The main water loss for cod muscle started at about 30°C and for salmon at about 35°C. However, cod and salmon muscle underwent almost the same structural changes, and in cod swollen/melted collagen could be observed in the whole muscle cell at 20°C using microscopy technics. Although the fish in our study were cold smoked (18-24°C), increased gaping in the smoked fish may therefore be due to structural changes in myocommata. Furthermore, gaping slits may also have been easier to register in the smoked fillets because of the dried surface, thus perhaps giving rise to a seemingly higher incidence of gaping after smoking.

The observation that gaping in salmon increased significantly with storage time on ice concurs with the findings of Bremer & Hallet (1985) who studied Blue grenadier (*Macruronus novaezelandiae*). These authors studied the collagen structure before, during and just after rigor mortis and found it intact. After chilled storage, however, the fibrils deteriorated and the muscle fibres gradually detached from the myocommata. The collagen is probably destroyed by collagenases and proteases. Montero & Borderias (1990) found that in trout (*Salmo irideus* Gibb) the solubility of collagen and proteolytic activity increased during storage. Combining this with the fact that consistent evaluation of gaping was found between fish given the same exterior classification (superior or ordinary) in different factories makes it more likely that treatment before filleting and storage conditions are more important factors to take into account in relation to gaping in salmonoids than quality class.

Chemical composition of fillets with and without gaping

Love & Robertson (1968) observed a correlation between gaping and moisture content in cod (*Gadus morhua* L); it was found that with a moisture content above 82.5% there was no gaping. In cod this is probably related to changes in pH, since pH increases when water content increases (Love 1988). Our results in salmon also revealed negative correlation between pH and both solids and fat content. However, fillets with gaping had the highest pH, even though the differences were quite small. This is in contrast to studies in cod (*Gadus morhua* L), whiting (*Gadus merlangus* L.) and haddock (*Gadus aeglefinus* L) (Love & Haq 1970) showing more gaping at low pH levels than at high pH. Mechanical studies of isolated connective tissue of cod show that it is very sensitive to changes in pH concentration. A decrease in pH of as little as 0.2 units may give a visible increase in gaping (Love 1988). Salmonoids, however, seem to be less influenced by pH changes (Lavèty et al. 1988), probably due to stronger connective tissue. Gaping due to an extensive lowering in pH may be less important in salmon.

Although Thomassen & Rye (1988) found a weak negative correlation between fat content and gaping in farmed salmon, other investigators (Stefanussen 1986; Thorsen 1989) have suggested that a high fat content increases gaping. In the present study, no differences in fat content were observed between fish with and without gaping, suggesting that fat content is not an important influential factor in the gaping process in salmonids.

In the combined material, fat and solids were positively correlated and both were negatively correlated with protein. These results substantiate earlier reports on farmed salmonids, also showing great differences in fat content and moisture and less variation in protein (Gjerde 1986). Thorsen (1989) found that fat content in farmed Norwegian salmon varied from 6 to 20% with an average at 15%. The two selections of fish evaluated in the present study were delivered from different fish farms. Different treatments before slaughtering, such as feeding, feed composition and length of starvation period may explain the differences in fat and protein observed between the two selections.

Texture measurements of fillets with and without gaping

In texture measurements, selection 1 showed less resistance against depression than selection 2, which may indicate a softer texture in the former. This may be related to the observed differences in chemical composition between the two selections. Thus, Thomassen & Rye (pers. comm., 1988) found a positive correlation between protein and sensorically evaluated firmness in boiled salmon. Furthermore, the higher fat content in selection 1 may have contributed to a softer texture in these fillets.

The results from the elasticity and depression measurements indicate that fillets with gaping have a weaker structure and offer less resistance against mechanical treatment than fillets without gaping. As mentioned earlier, Bremer & Hallet (1985) suggest that gaping may be due to weakened connective tissue caused by proteolytic enzymes. Individual differences in collagen content may, furthermore, be of importance. Sato et al. (1986) studied differences between species and found that gaping and fish texture were dependent on the content of collagen. In species in which the muscle collagen content was relatively high, the texture was less tender or even tough. Less gaping is also observed in fish with a high amount of connective tissue. Salmonoids are among species with a low collagen content (Sato et al. 1986).

Handling before slaughter, and gaping

Although no statistically significant differences were observed, roughly handled fish tended to have more gaping, which concurs with the impression among workers in the salmon industry concerning handling and transport before slaughter. No differences could be observed, however, in the texture measurements performed. Colour measurements were also included in this comparison, but no statistically significant differences were found. The sensory test indicated differences in the texture attribute juiciness. Furthermore, significant differences were observed in total taste impression and in salmon taste. The stronger taste in carefully treated fish is perhaps due to a more rapid ATP degradation in the roughly handled fish. ATP degradation products can influence taste; ATP is degraded to ADP and then to IMP which is a taste fortifier. IMP is further degraded to inosine and hypoxanthine. Inosine has no taste whereas hypoxanthine is bitter (Huss 1983). A more rapid degradation in the roughly handled fish may have produced more inosine in these fish than in the carefully treated fish which may have been dominated by the taste fortifier IMP.

The results from this study suggest that differences in handling before slaughter may influence both the fish texture, taste, and chemical composition. However, more research is necessary to establish the significance of these effects and the mechanisms responsible for the observed changes.

SUMMARY

Registration of fillet gaping was carried out in three Norwegian factories processing farmed Atlantic salmon (*Salmon salar*) to estimate the extent of this texture problem. Gaping was evaluated by using a scale from 0 to 5, where 0 indicated no gaping and 5 extreme gaping. In two of the factories, 22-25% of the fillets were evaluated as scoring 3 or 4 on the scale. In one of the factories the economic loss due to gaping was estimated at 5-10%. It was found that storage time on ice significantly increased gaping.

Two separate selections of salmon fillets, 10 fillets with and 10 fillets without gaping, were compared. In the first selection the mean fat content, was higher and texture measurements (Instron) revealed a softer consistency than in fillets from the second selection. Within each selection, however, fish with and without gaping showed no significant difference in fat content. In one of the selections, fillets without gaping had a significantly higher protein content. Resistance against compression as well as elasticity was reduced in fillets with gaping.

An experiment was also carried out to study a possible relationship between treatment before slaughter and gaping. Fifteen fish were roughly handled before slaughtering and then compared with 15 carefully handled fish from the same net pen. Although no statistically significant differences were observed, fillets from the roughly handled fish tended to have more gaping, and a lower pre-rigor glycogen content. Sensory analyses revealed stronger taste attributes in the carefully handled fish. Rough handling before slaughter may therefore influence both texture and taste attributes in salmon fillets.

In conclusion, the present investigation demonstrates that gaping in fillets represents a serious problem in the salmon processing industry. The results further indicate that time-

dependent degradation in salmon muscle structure may play a greater role in the development of this problem than changes in pH due to glycogen degradation.

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Moose (*Alces alces*) and mountain hare (*Lepus timidus*) use of conifer plantations following glyphosate application

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Hjeljord, O. 1994. Moose (*Alces alces*) and mountain hare (*Lepus timidus*) use of conifer plantations following glyphosate application. Norwegian Journal of Agricultural Sciences 8: 181-188. ISSN 0801-5341.

Reinvasion of hardwoods and use of forest plantations by moose (*Alces alces*) and mountain hare (*Lepus timidus*) after the application of glyphosate were studied for 9 years in southeastern Norway. Hardwoods and pellets (feces) of moose and hare were recorded on permanent plots on sprayed and control sites. Nine years after spraying the number of trees was 76% of that on control sites, while shoot production remained small. *Sorbus aucuparia* almost disappeared on sprayed sites and on unsprayed sites was prevented from increasing in height by heavy moose browsing. Therefore, *Betula* sp. dominated on both sprayed and unsprayed sites 9 years after spraying. Hare use of sprayed sites decreased during the first year after spraying, but thereafter did not differ from use of control sites during the rest of the study period. Moose use of sprayed sites was lower during all years except one.

Key words: Browse production, forest plantations, glyphosate, hardwood growth, moose, mountain hare.

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Re-establishment of hardwoods and wildlife use of forest plantations after glyphosate application were studied on three sites in southeastern Norway during the years 1983-86 (Hjeljord & Grönvold 1988; Hjeljord et al. 1988; Eggestad et al. 1988). Regrowth of hardwoods after spraying was negligible during the three years of study (Hjeljord & Grönvold 1988) and moose use of sprayed sites was significantly lower than use of adjacent control sites (Hjeljord & Grönvold 1988). Hare use of sprayed sites was recorded on one of the plantations (Bjørkenessjøen), but with the exception of the first year after spraying, when use decreased significantly, hares used sprayed and control sites to the same extent (Hjeljord et al. 1988).

As three years is a short time for the study of plant succession on a recent clearcut, one of the plantations was selected for a follow-up study. Here we report hardwood re-establishment and moose and hare use of this plantation.

MATERIALS AND METHODS

The 21 ha forest plantation at Bjørkenessjøen (59°50'N, 11°40'E) was chosen for the study. The area was clearcut in 1976/77 and sprayed in 1983; two parts of the plantation were sprayed and two left as controls (Lund-Höie & Grönvold 1987) (Figs. 1 and 2).

Fig. 1. A section of the forest plantation in southeast Norway, used in the study, 12 years after clearcutting, with no regulation of hardwoods

Fig. 2. A section of the forest plantation (Fig. 1) 12 years after clearcutting and 5 years after spraying with glyphosate

Number and height of hardwoods were recorded on circular plots of 3 m radius laid systematically over the plantation. All trees higher than 0.3 m were recorded. Counts of moose pellet groups (feces) left during fall/winter were taken on the same plots, but the

radius of the plots was increased to 4 m. Hare pellets were counted on a part of the plot by placing four strips, each 4 m by 0.6 m, at right angles from the center of each plot. The counts of hare pellets were taken by two persons. All pellets were removed from the strips after counting and the number of trees and pellets were recorded immediately after snowmelt.

As all hardwoods were killed by the glyphosate treatment, trees recorded on treated sites were seedlings established after spraying. To determine the yearly twig production of unsprayed hardwoods, we used the correlation between tree height and yearly twig production already determined for the area (Hjeljord & Grönvold 1988). For the new growth of hardwoods on glyphosate-treated sites, a new set of correlation equations was determined following the procedure by Hjeljord & Grönvold (1988). Biomass of yearly shoot production per hectare was calculated by multiplying shoot production/tree by number of trees per hectare. It was assumed that trees higher than 4.5 m would have most of their branches beyond reach of moose and therefore they were not included in the calculation of browse production. The standard deviation of yearly shoot production was calculated using the method by Torp (1985).

RESULTS

The number of hardwood seedlings (*Sorbus aucuparia* and *Betula* spp.) on sprayed sites increased from 580 trees/ha, 3 years after spraying to 3850 trees/ha, 8 years after spraying (12 years after clearcutting). On the control sites there were 8930 trees/ha (12 years after clearcutting). Twig production within reach of moose on sprayed sites was negligible in 1986 but had increased to 14.5 kg/ha in 1991, compared with 97.2 kg/ha on control sites (Figs. 3 and 4).

S. aucuparia almost completely disappeared from sprayed sites. While the proportion (number of trees) of *S. aucuparia* to Betula spp. was 38:68 before spraying, this had decreased to 6:94 8 years after spraying (Figs. 3 and 4). On the control sites, *S. aucuparia* stagnated in height increment and therefore decreased in dominance compared to *Betula* sp. This was due to heavy browsing from moose, keeping the height of *S. aucuparia* below 1 m. Within a 25 m^2 enclosure established in 1983 in Vestfold in a plantation of mixed *Betula* spp. and *S. aucuparia* (Hjeljord & Grönvold 1988), *S. aucuparia*, thus protected from moose browsing had reached an average height of 3.8 m in 1991, compared with 0.8 m for moose-browsed trees outside the fence (Fig. 5).

Eight years after spraying, the number of birch trees on glyphosatetreated sites was not significantly different from that of untreated controls ($p > 0.05$) (Fig. 3). The much slower recovery of shoot production of birch after spraying (15% of the production on control sites, 8 years after spraying) compared to the increase in number of trees (76% of numbers on control sites) is due to differences in tree growth form. The seedlings invading the plantation after spraying were fragile and slender with few shoots compared to the vigorous and well-branched trees of the primary succession. The decrease in browse production on control sites (Fig. 3) was due to *Betula* spp. higher than 4.5 m being excluded from the calculation of browse production.

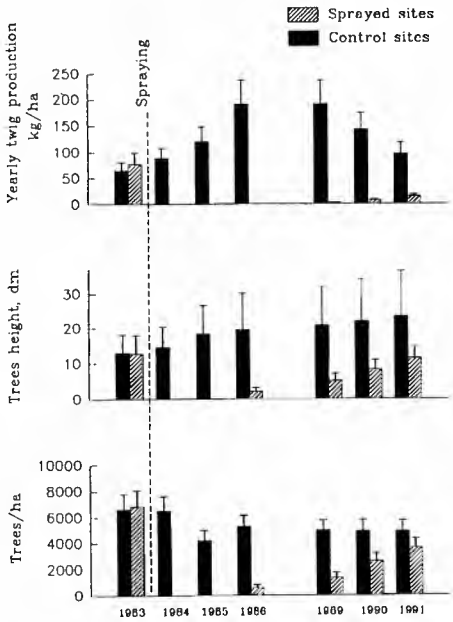

Fig. 3. Regrowth of *Betula* sp. on sections of the forest plantation sprayed with glyphosate in 1983, compared with that on untreated control sites. Vertical bars indicate the standard error (SE)

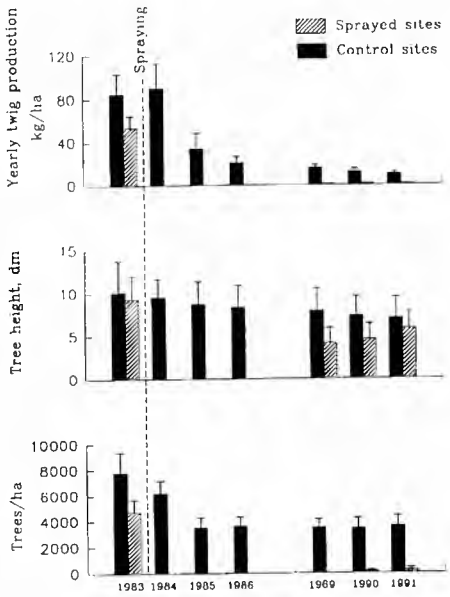

Fig. 4. Regrowth of *Sorbus aucuparia* on forest plantation sprayed with glyphosate in 1983, compared with that on untreated control sites. Vertical bars indicate the standard error (SE)

Fig. 5. Protected against moose browsing, *Sorbus aucuparia* within an enclosure have reached an average height of 3.8 m 12 years after clearcutting

Moose usage of sprayed sites remained small compared to that of controls. There was no change in use of sprayed sites between the first period (1984-86) and the last period (1989-91) (Table 1).

Table 1. Number of moose (*Alces alces*) pellets groups (feces) per registration plot on untreated (control) and glyphosate-treated (sprayed) parts of the forest plantation (Figs. 1 and 2)

Year	Control I and II N[1] = 98	Sprayed I and II N = 140	Level of significance [2]
1983	0.5	0.6	NS
Spraying			
1984	0.5	0.2	*
1985	1.2	0.8	NS
1986	1.0	0.4	*
1989	0.4	0.1	*
1990	0.8	0.1	*
1991	0.6	0.2	*

[1] Number of registration plots

[2] Difference from control * = $p<0.05$, NS not significant at 5% level

With the exception of the first year after spraying, there was no significant difference in hare use of sprayed and unsprayed sites during either the first or the second period. The

pellet density decreased significantly on the southern part of the study area (control I, sprayed I), but remained stable on the northern part (control II, sprayed II) (Table 2).

Table 2. Number of hare (*Lepus timidus*) pellets (feces) per registration strip on untreated (control) and glyphosate-treated (sprayed) parts of the forest plantation (Figs. 1 and 2)

Year	Control I (N[1] = 60)	Sprayed I (N = 110)	Control II (N = 38)	Sprayed II (N = 30)
1983	12.1	10.8	3.1	5.7
Spraying				
1984	11.5	2.9*[2]	5.8	0.5*
1985	37.6	27.2 NS[2]	7.6	4.7 NS
1986	24.5	15.5 NS	8.3	3.4 NS
1989	8.4	12.6 NS	7.4	5.7 NS
1990	11.5	10.2 NS	3.5	5.8 NS
1991		8.3	7.9	2.3 NS

[1] N = Number of registration plots
[2] Difference from control * = $p<0.05$, NS not significant at 5% level

DISCUSSION

On the sprayed sites at Bjørkenessjøen the number of hardwoods increased to 3850 trees/ha 8 years after spraying. This compares well with 2100 trees/ha and 5200 trees/ha recorded as an average on clearcuts 7 years after spraying within two larger survey areas in southeastern Norway (Solbraa & Lund-Höie 1989).

In general there appears to be a close relation between the efficiency of spraying and later re-establishment of hardwoods. Lund-Höie & Solbraa (1993) studied sprayed sites for 3 years after glyphosate application and found only insignificant regeneration of *Betula* spp. when the initial kill was complete, but a 90% regeneration when 17% of the seedlings survived spraying.

Low regeneration of *S. aucuparia* after spraying is documented in several studies. From a survey of several sprayed sites located in the same area as our study, Solbraa & Lund-Höie (1989) found almost the same proportion of *S. aucuparia* to *Betula* (7:93) as we did (6:94). In another study, Lund-Höie & Solbraa (1993) found the maximum regeneration of *S. aucuparia* to be 11%, compared with 90% for birch. Probably the lack of berryproducing *S. aucuparia* trees in the vicinity of the clearcuts is a major reason for the slow regeneration of this species after spraying. Apparently, the dense primary growth of *S. aucuparia* on the plantation after clearcutting was due to rootsuckers and stump sprouts that were present in the mature forest before cutting.

During their two-year study, Lund-Höie & Andersen (1993) recorded a decrease in *S. aucuparia* seedlings on undisturbed plantations 4-5 years after logging. Our data from control sites show a similar decrease in seedlings from the seventh to the eighth year after

logging, while there is a stabilization from the ninth year onwards. We also recorded a decrease, although of smaller magnitude, in *Betula* sp. seedlings. Lund-Höie & Andersen (op. cit.) found an increase in birch seedlings.

Nine years after spraying, birch is dominant on both sprayed and unsprayed sites. On the latter this is due to moose browsing, which keeps *S. aucuparia* below the height of 1 m.

Despite of a much higher biomass (80-90%) of hardwoods on control sites compared with that on sprayed sites during the last study period (1989-91), there has been no difference in use of the control sites mountain by mountain hare compared to sprayed sites. This is surprising, as bark and twigs of hardwoods are a staple food of hare during winter (Hjeljord et al. 1988; Lindlöf et al. 1974). However, hare prefer the crowntwigs of taller trees of *Betula* sp. (Klein 1977; Hjeljord et al. 1988). During the last study period, snowfall was light and probably insufficient for bending the taller *Betula* sp. to the ground, within reach of hares. Apparently, therefore, both sprayed and unsprayed sites are used mostly during early spring when hares feed on grasses and herbs on exposed ridges (Hjeljord et al. 1988).

The negligible use by moose of the sprayed sites corresponds with the strong reduction in browse biomass. On clearcuts of this site, the quantity of browse has not regenerated sufficiently to attract moose, even 6-9 years after the application of glyphosate.

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Forest fungal diseases of Tanzania: background and current status

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A review of the background and current status of forest diseases in Tanzania is presented in this article. Outbreaks of the most destructive exotic and indigenous diseases are addressed and currently known diseases of both indigenous and exotic trees, including ornamental and agroforestry trees, are tabulated to form a preliminary checklist. It is concluded that more knowledge on forest diseases is still required and therefore further research is necessary to reveal the full extent of the diseases in both natural and plantation forests.

Key words: Check list, forest diseases, fungal pathogens, Tanzania.

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Tanzania has a vast forest area which covers 44 million ha (about half the country's total area) of which 80,000 ha comprises plantations. These forests have about 10,000 species of indigenous higher plants (Polhill 1968) of which more than 1,200 are tree species (Wilan 1965). If conservation and productivity are to be sustained, the natural and plantation forests will have to be protected against fire, indiscriminate cutting, encroachment and, equally importantly, against pests and diseases. Whilst the protection of the forests against hazards which are related to human activities can partly be achieved through law enforcement and use of extension services, protection against diseases requires, in addition, a much more integrated approach incorporating specialized knowledge on the types and nature of the diseases. Full utilization of such an approach has not yet been achieved, due to insufficient knowledge about diseases of many tree species growing in the country. This deficiency is also one of the major problems facing forest managers in the monitoring and reporting of diseases which prevail in their forests. This implies also that if such knowledge were available it would be incorporated in formulating management programmes involving protection of forests against potential diseases. Therefore, the role of research in providing such knowledge is of utmost importance.

Any information on tree diseases in Tanzania (for both indigenous and exotic trees, including ornamental and agroforestry trees) which is available today tends to be diffuse,

and the aim of this review is therefore to explain how the existing knowledge about forest diseases came about and to compile a list of the diseases that are currently scattered in various literature as a basis for reference and future work. This is achieved by presenting the background to forest disease research and knowledge in the country, discussing the most important disease outbreaks which have occurred, and then tabulating the currently known diseases of both indigenous and exotic trees, including ornamental and agroforestry trees.

BACKGROUND TO FOREST DISEASE RESEARCH AND KNOWLEDGE

In East Africa, research in plant diseases including forest trees was conducted after the World War II by the then East African Agriculture and Forestry Research Organization (EAAFRO) which came under the auspices of the now defunct East African Community. EAAFRO catered for Tanzania, Kenya and Uganda. The section in EAAFRO dealing with forest diseases was formed as a result of an increase in disease outbreaks in exotic tree plantations (Gibson 1965a) which were established to supplement timber production from the natural forests. Research reports which are currently available indicate that the emphasis was on diseases of exotic trees such as pines, cypress, eucalyptus, teak, and others grown in E. Africa. Some diseases of indigenous trees of Tanzania are mentioned in some checklists (e.g. Riley 1960; Peregrine & Siddigi 1972; Ebbels & Allen 1979) which give the names of the host and pathogen and the kind of disease caused. Research reports by EAAFRO provide details on the infection biology, spread, economic impact of the diseases and the limitations to most pathogens in the case of exotic plantation trees while very few indigenous trees were covered in such detail. Sometimes pathological defects of indigenous trees of economic importance were mentioned in other fields of forestry, such as mensuration (e.g. Paterson 1965).

After the departure of most expatriate staff from EAAFRO and the break-up of the East African Community in February 1977, very little research was conducted in both the plantations and the natural forests due to the lack of/or very few local forest pathologists. The bulk of knowledge on forest diseases of indigenous and plantation forests and in related fields such as mycology is thus currently limited to reports by the EAAFRO and a few researchers who either visited the country or worked in the government departments of agriculture or forestry. Most of the work is chiefly acknowledged to the invaluable contribution by researchers from Britain, Nordic/Scandinavian and North American countries and the FAO who worked in, or visited E. Africa in the past. The researchers were plant pathologists or mycologists and some of the most important reports are those by Gibson (1956, 1957, 1960, 1962, 1965a, 1965b, 1966a, 1966b, 1967, 1968, 1975), Gibson & Corbett (1964), Procter (1965, 1967), Ivory (1967), Griffin (1967, 1968), Hocking & Jaffer (1967), Hocking (1968), Howland & Gibson (1969), Olembo (1969, 1972), Ryvarden (1972), Allen (1975a, 1975b), Ebbels & Allen (1979) and Ryvarden & Johansen (1980). Since then, only a very small amount of research has been accomplished by local and visiting researchers (e.g. Waring 1982; Diwani et al. 1984; Canon 1985; Tangwa et al. 1988; Renvall & Niemela 1993), and therefore, the gap in knowledge on diseases of indigenous trees and fungi in general is still enormous.

FOREST DISEASE OUTBREAKS

The introduction of exotic tree species provided an opportunity for the emergence of new diseases which were previously only found in the native countries (Gibson 1967; Griffin 1968). Root pathogens such as *Poria* sp., *Helicobasidium compactum* and *Ustulina deusta* were introduced in E. Africa with the exotics (Griffin 1968). Today, there is a considerable risk of loss from diseases in many tree species due to the increase in the number of pathogens.

Among the most serious diseases which were "imported" are the *Dothistroma* blight of pines caused by the ascomycete fungus *Mycosphaerella pini* (syn. *Scirrhia pini*, imperfect stage: *Dothistroma pini*), the cypress canker caused by *Rhynchosphaeria cupressi* (syn. *Leptentypa cupressi*; imperfect stage: *Monochaetia unicornis*) and, recently, a severe leaf spot disease of *Eucalyptus maidenii* caused by *Mycosphaerella molleriana* (imperfect stage: *Sphaeropsis molleriana*).

The *Dothistroma* blight, first observed in northern Tanzania in 1958 at Shume forest plantations (Ivory & Paterson 1970), spread vigorously and virtually wiped out the young plantations of *Pinus radiata* in E. Africa and Malawi within 20 years. The disease led the governments of E. Africa to abandon further planting of *P. radiata* in 1964 (Diwani et al. 1984) and the government of Malawi to clearfell its last compartment of *P. radiata* in 1978 (Zulu 1991). *P. radiata* was a superior conifer tree in terms of wood quality and was comparable to the most durable indigenous timber trees growing in the region. Similarly, the planting of *Cupressus macrocarpa* (which was very susceptible to the *Monochaetia* canker) had been stopped earlier in E. Africa in the early 1950s and replaced with *C. lusitanica*, which is less susceptible to the pathogen (Olembo 1969).

The leaf spotting fungus *M. molleriana* (first observed in Tanzania in 1991) has attacked *Eucalyptus maidenii* throughout the country causing severe necrotic spots leading to foliage drying and defoliation in nursery seedlings, coppice sprouts and in young plantation trees which have not acquired their mature foliage form. Mature foliage is also attacked in some trees but the damage is mild when compared to the juvenile foliage and no defoliation occurs. There is a possibility that the pathogen has spread throughout E. Africa due to similarity in the climate throughout the region. The fungus was previously reported in Brazil as "unusually severe" (Gibson 1975) and as "serious" in Malawi (Zulu 1991). In South Africa, a mycosphaerella leaf disease was first reported on an unspecified *Eucalyptus* sp. as early as 1923, but a few years later it was reported as "very serious" on *E. maidenii* and *E. globulus* to the extent that the two eucalyptus species were abandoned as commercial forest species of South Africa (Lundquist 1987). Three species of this fungal genus, namely *M. molleriana, M. heimii* and *M. nubilosa*, have been reported to attack foliage of eucalyptus trees in Africa (Gibson 1975). In South Africa the *Mycosphaerella* leaf disease has been found on 10 eucalyptus species and pathogens were identified as being *M. molleriana* and *M. nubilosa* (Lundquist 1987). This therefore implies that Tanzania is facing yet another serious disease outbreak which is capable of causing great damage to the many eucalyptus species growing in the country.

Serious indigenous diseases also exist which have caused an unquantified amount of loss to economically important timber trees. Among these diseases is the heart rot of stem of *Ocotea usambarensis* (East African camphor tree) which has been attributed to a number

of basidiomycete fungi with the most widely reported pathogen being *Phellinus senex* (syn. *Fomes senex*; *Polyporus senex*). There are many fungi that attack the tree species and the ones that are most likely to cause decay are mentioned by Ebbels & Allen (1979) and Renvall & Niemelä (1993). Damage to the tree by the pathogens is enormous and in most localities where this species grows, for example the Uluguru mountains, its regeneration capacity has been affected because many stumps which could have had coppice or root sucker regeneration are simply rotting away (Mwamba 1986). In its favourite habitats in the Usambara and Kilimanjaro mountains the species is also in decline, which is manifest in some trees of all age classes as dieback of leading branches and stem-decay symptoms. Hamilton et al. (1989) described the virtual total lack of regeneration of *O. usambarensis* in the East Usambara mountains as a "remarkable feature", suggesting the severity of the problem. The species used to be a potential commercial tree which provided round and sawn timber for local and export markets, but now its supply has been greatly affected by the decay diseases.

Another native disease is the root rot of numerous tree species caused by *Armillaria mellea* (s.l). It has been reported that *A. mellea* destroyed 66% of a large compartment of pines and *Grevillea robusta* trees (specific size unspecified) at Usa River in the Mount Meru Forest Project, northern Tanzania (Diwani et al. 1984).

The presence of indigenous and exotic trees in the same ecosystem creates possibilities for the exotic pathogens to attack indigenous hosts and the indigenous pathogens to attack the exotic hosts. This interaction brings about a complex combination of disease problems which could probably be easily controlled in the native ecosystems. For example, the tropical trees are said to be only slightly susceptible to infection by *A. mellea* root disease, but when a conifer plantation is established on a site with contaminated stumps or other plant debris from a cleared natural forest, heavy damage to the conifers is normally expected (Gibson 1960; Olembo 1972). This also means that new strains of disease agents (which could be more virulent) could have evolved to attack new hosts as a result of changes in climate and food characteristics. Gibson & Corbett (1964) found that *A. mellea* in Malawi existed in various forms while the same situation has been found also in Europe (e.g., Raabe 1980). Today, *Armillaria* is the most widely reported disease found on 15% of all the tree species reported to have one or more diseases (see Tables 1 and 2). The extent to which the exotic pathogens have spread and infected the indigenous hosts in Tanzania has yet to be determined because no comprehensive surveys have been conducted in the natural forests.

KNOWN DISEASES OF INDIGENOUS AND EXOTIC TREES

Research during the past 50 years has shown an increase in the number of forest disease outbreaks in Tanzania. This fact is partly explained by Tables 1 and 2 which present the currently known diseases of indigenous and exotic trees, respectively. The tables form a preliminary checklist into which new diseases (formerly unidentified or unreported) can be added. The information has been gathered from various reports written since the introduction of forest disease research in East Africa.

Table 1. Known fungal diseases of indigenous tree species in Tanzania

Tree species	Pathogen	Disease/part infected	
ADANSONIA DIGITATA	*Leveillula taurica* (mildew)	Leaves	(6)[1])
AFZELIA QUANZENSIS	*Microstoma* sp.	White leaf spot	(2)
ALBIZIA VERSICOLOR	*Phomopsis mendax*	Dieback	(6)
ALBIZIA PETERSIANA	*Phomopsis mendax*	Dieback	(6)
ANTHOCLEISTA ORIENTALIS	*Pucciniosira mitragynes* (Rust)	Leaves	(6)
ARUNDINARIA ALPINA	*Engleromyces goetzii*	Stem canker	(6)
BRACHYSTEGIA SPICIFORMIS	*Oidium* sp. (mildew)	Leaves	(2)
	Phyllachora brachystegiae	Leaf spot	(2)
BRACHYSTEGIA SP.	*Perisporiopsis brachystegiae*	Black spots on leaves	(6)
CALODENDRUM CAPENSE	*Phloeospora* sp.	Leaf spot	(6)
CASSIA SINGUEANA	*Ravenelia baumiana* (Rust)	Leaves	(2)
CEPHALOSPHAERA USAMBARENSIS	*Armillaria mellea* s.l.	Root rot	(30)
COMBRETUM MOLLE	*Uredo combreticola* (Rust)	Leaves	(1)
COMBRETUM PURPUREIFLORUM	*Aecidium* sp. (Rust)	Leaves	(2)
DALBERGIA NITIDULA	*Mycosphaerella dalbergiae*	Leaf spot	(6)
	Phomopsis dalbergiae	Leaf spot	(6)
	Phyllachora dalbergiae	Leaf spot	(2)
	Uredo sp. (rust)	Covers foliage	(2)
ELAEIS GUINEENSIS (oil palm)	*Cercospora elaeidis*	Leaf freckle	(6)
	Pestalotiopsis palmarum	Leaf spot	(6)
EUPHORBIA TIRUCALLI	*Sphaeropsis euphorbiae*	Stem canker	(6)
HARUNGANA MADAGASCARIENSIS	*Pestalotia harongae*	Leaf spot	(6)
JUNIPERUS EXCELSA (PROCERA)	*Antrodia juniperina* (syn. *Agaricus juniperina*)	Cubical stem rot	(43)
	Calisopsis nigra	Galls	(6)
	Daedalea juniperina	Stem rot	(6)
	Daedalea quercina	Cubical stem rot	(6)
	Omphalotus olearius	Stump decay	(6)
	Pyrofomes demidoffii (syn. *Polyporus demidoffii*)	Branch/stem rot(Pers. Comm.) [2])	
	Ganoderma luccidum	Stem rot (Pers. Comm.)	
KHAYA ANTHOTHECA (NYASICA)	*Meliora khayae*(Sooty mildew)	Premature defoliation	(6)
MACARANGA KILIMANDSCHARICA	*Englerula macarangae*	Leaves	(2)
MAESOPSIS EMINII	*Fusarium solani*	Stem canker	(6)
MARKHAMIA OBTUSIFOLIA	*Cladosporium oxysporum*	Leaf blight	(2)
	Mycosphaerella sp.	Leaf blight	(2)
MILICIA (CHLOROPHORA) EXCELSA	*Armillaria mellea* s.l.	Root rot	(20)
	Helicobasidium brebissonni (syn. *H.purpureum, Rhizoctonia crocorum*)	Purple butt/root rot	(20)
NUXIA CONGESTA	*Phellinus punctatus*	Stem rot (Pers. Comm.)	
	Oxyporus populinus	Stem rot (Pers. Comm.)	
OCOTEA USAMBARENSIS	*Armillaria mellea* s.l.	Root rot (Pers. Comm.)	
	Loweporus inflexibilis	Root and butt rot	(40)
	Pestalotiopsis sp.	Leaf blotch (Pers. Comm.)	
	Phellinus (Fomes) allardii	Stem dacay	(40)
	Phellinus apiahynus	Root and stem decay	(40)
	Phellinus senex	Heart rot	(10)
	Stereum hirsutum	Streaked white rot	(6)
OLEA CAPENSIS (WELWITSCHII)	*Alternaria porri*	Seedling leaf spot	(6)
	Alternaria tenuissima	Seedling collar rot	(6)
	Cladosporium oxysporum	Seedling leaf spot	(2)
	Macrophomina phaseolina	Seedling collar rot	(6)
	Meliora petiolaris (Sooty mildew)	Leaf spot/defoliation	(2)
	Myrothecium verrucaria	Seedling collar rot	(6)

Table 1. Cont.

Tree species	Pathogen	Disease/part infected	
PACHYSTELA MSOLO	*Helminthosporium pachystelae*	Leaf spot	(6)
PODOCARPUS USAMBARENSIS	*Ganoderma australe*	Stem rot	(Pers. Comm.)
RAPANEA SP.	*Stereum hirsutum*	Timber decay	(6)
STERCULIA AFRICANA	*Macrophyllosticta sterculiae*	Leaf net-spot	(6)
STOEBE KILIMANDSCHARICA	*Aecidium elytropappi* (Rust)	Leaves	(6)
STRYCHNOS POTATORUM	*Cercospora strychni*	Leaf blight	(6)
	Mycosphaerella sp.	Leaf spot	(6)
	Sirosporium sp.	Leaf blight	(6)
STRYCHNOS STUHLMANII	*Phyllosticta strychni*	Leaf spot	(6)
SYNADENIUM GRANTII	*Phyllosticta* sp.	Leaf spot	(2)
TAMARINDUS INDICA	*Gloesporium tamarindi*	Leaf spot	(6)
	Mycosphaerella tamarindi	Leaf spot	(6)
TECLEA NOBILIS	*Puccinia tecleae (rust)*	Leaves	(6)
TECLEA SIMPLICIFOLIA	*Puccinia tecleae*	Leaves	(6)
TRICHILIA EMETICA (ROKA)	*Cercospora* sp.	Leaf spot	(6)

[1]) Numbers in parentheses correspond to the numbers given in the list of references to indicate the source of the information. For convenience, only one reference per disease is provided
[2]) Pers. Comm. = Personal Communication

Table 2. Known fungal diseases of exotic tree species in Tanzania

Tree species	Pathogen	Disease/part infected	
ACACIA MEARNSII (MOLLISMA)	*Poria vincta* var. *cinerea*	Root rot	(6)[1])
	Stereum hirsutum	Timber decay	(6)
ACACIA MELANOXYLON	*Poria vincta* var. *cinerea*	Root rot	(6)
ACACIA SPP.	*Ravenelia volkensii*	Witches broom	(6)
	Armillaria mellea s.l.	Root rot	(6)
ALBIZIA LEBBECK	*Phomopsis mendax*	Dieback	(2)
	Uredo ngamboensis (rust)	Defoliation	(6)
ANACARDIUM OCCIDENTALE (cashew)	*Gliocladium roseum*	Dieback	(6)
	Oidium anacardii (mildew)	Kills inflorescence	(Pers. Comm.)[2])
BAUHINIA SP.	*Oidium* sp.	Pods	(6)
CAMELLIA SINENSIS	*Phomopsis theae*	Collar and branch canker	(6)
CASSIA ABSUS	*Ravenelia berkleyi* (Rust)	Leaves	(2)
CASSIA ALATA	*Phomopsis cassiae*	Wilt and Dieback	(6)
CASSIA FLORIBUNDA	*Macrophomina phaseolina*	Black root rot	(18)
CASSIA LAEVIGATA	*Macrophomina phaseolina*	Black root rot	(18)
CASSIA OBTUSIFOLIA	*Aecidium cassiae* (Rust)	Leaves	(6)
	Fusarium sp. (?*F. avenaceum*)	Stem canker	(6)
	Oidium sp.	Leaves	(6)
CASSIA OCCIDENTALIS	*Oidium* sp.	Leaves	(6)
	Pseudoperonospora sp.	Disc-spot of leaves	(6)
CASSIA SENNA	*Corticium rolfsii*	Wilt	(18)
	Fusarium oxysporum	Seedling death	(6)
CASSIA SIAMEA	*Cercosporidium cassiae*	Defoliation	(18)
	Oidium sp.	Defoliation	(1)
	Polyporus baudoni	Root rot	(35)

Table 2. Cont.

Tree species	Pathogen	Disease/part infected	
CASSUARINA MONTANA	*Armillaria mellea* s.l.	Root rot	(6)
CEDRELLA SPP.	*Armillaria mellea* s.l.	Root rot	(18)
	Ceratocystis moniliformis	Dieback	(18)
CINNAMOMUM CAMPHORA	*Armillaria mellea* s.l.	Root rot	(6)
CINNAMOMUM ZEYLANICUM	Colletotricum cingulata	Leaf spot	(6)
	Phyllosticta sp.	Leaf spot	(6)
CITRUS AURANTIFOLIA (lime)	*Gloeosporium limetticola*	Withertip	(6)
CITRUS LIMON (lemon)	*Alternaria citri*	Leaf spot	(6)
	Fusarium sp.	Rough lemon of nursery seedlings	(6)
CITRUS PARADISI (grape fruit)	*Fusarium solani*	Root gummosis	(6)
CITRUS SINENSIS (orange)	*Phytophthora nicotianae* var.*parasitica*	Gummosis	(6)
COCOS NUCIFERA (coconut)	*Asteridium ferrugineum*	Sooty mould	(6)
	Ganoderma sp.	Stem rot	(6)
	Gloesporium sp.	Nut fall and calyx end rot	(6)
	Lasmeniella cocoes	Leaf spot	(6)
	Marasmiellus coccophilus	Lethal bole rot	(6)
	Phytophthora palmivora	Nut fall and Calyx end rot	(6)
	Pseudoepicoccum cocos	Zonate leaf spot	(6)
	Zukalia stuhlmanniana (Sooty mould)	Leaves	(6)
CUPRESSUS ARIZONA	*Rhynchosphaeria cupressi*	Stem canker	(32)
CUPRESSUS LINDLEY	*Rhynchosphaeria cupressi*	Stem canker	(5)
CUPRESSUS LUSITANICA	*Armillaria* s.l.	Butt rot	(33)
	Coriolus versicolor	White sap rot of timber	(6)
	Fusicoccum tingens	Associated with death of young trees	(6)
	Peniophora ceberella	Butt rot	(6)
	Poria vincta var. *cinerea*	Root rot	(6)
	Poria vaillantii	Brown cubical rot of timber	(6)
	Rhynchosphaeria cupressi (syn. *Leptentypa cupressi*)		
(Imperfect stage:	*Monochaetia unicornis*)	Stem canker	(6)
DELONIX (PONCIANA) REGIA	*Inonotus ochroporus*	Wood rot	(6)
EUCALYPTUS MAIDENII	*Mycosphaerela molleriana*		
(Imperfect stage:	*Sphaeropsis molleriana*)	Leaf spot & defoliation	(Pers.Comm.)
EUCALYPTUS SPP.	*Armillaria mellea* s.l.	Root rot	(18)
EUGENIA AROMATICA (clove)	*Armillaria mellea* s.l.	Root rot	(18)
	Botryodiplodia sp.	Seedling death	(6)
	Endothia eugeniae	Dieback	(6)
	Valsa eugeniae	Sudden death of trees	(6)
EUGENIA JAMBOS	*Endothia eugeniae*	Dieback	(6)
FICUS ELASTICA	*Colletotricum cingulata*		(6)
	(Perfect state: *Glomerella cingulata*)	Leaves	(6)
	Phoma atrocincta	Petiole	(1)
GMELINA ARBOREA	*Irpex flavus*	White sap rot of logs	(35)
	Polyporus baudoni	Root rot	(35)
	Xylosphaera (Xylaria) multiplex	Butt rot and death	(6)
GREVILLEA ROBUSTA	*Armillaria mellea* s.l.	Root rot	(5)
MANGIFERA INDICA	*Capnodium mangiferae*	Leaf spot	(6)
	Dimerosporium mangiferae	Sooty mould	(6)
	Phyllostica mangiferae	Leaf spot	(6)
PARKINSONIA ACULEATA	*Ganoderma vanmeelii*	Wood rot	(6)
PERSEA AMERICANA	*Curvularia intermedius*	Leaves	(6)

Table 2. Cont.

Tree species	Pathogen	Disease/part infected	
PHOENIX DACTYLIFERA	*Zukalia stuhlmanniana*	Leaves	(6)
PINUS SPP.	*Alternaria* sp.	Tip dieback, *P. patula*	(6)
	Armillaria mellea s.l.	Root rot	(9)
	Botryodiplodia theobromae (syn. *Diplodia natalensis*)	Needle blotch	(24)
	Cercospora pini-densiflorae	Needle blight	(6)
	Cladosporium sp.	Seedling browning and dieback in *P. patula*	(6)
	Fusarium oxysporum	Tip blight of *P. patula*	(6)
	Fusarium sp.	Damping off	(7)
	Fusicoccum tingens		
(Perfect stage:	*Botryosphaeria ribis*)	Dead top of *P. patula* & *P.radiata*; Dieback of *P. caribaea*	(25)
	Mycosphaerella pini (syn. *Scirrhia pini*)		
(Imperfect stage:	*Dothistroma pini*)	Needle blight in *P. radiata*, *P. caribaea* & *P. montezumae*	(6)
	Mycosphaerella pinicola	Needle blight	(6)
	Naemacyclus niveus	Needle cast, *P. radiata*	(6)
	Pestalotiopsis cruenta	Needle blotch and cast	(6)
	Phytophthora spp.	Damping off	(8)
	Pythium spp.	Damping off	(7)
	Sphaeropsis sapinea (syn. *Diplodia pinea*)	Shoot dieback	(24)
	Stereum sanguinolentum (Syn. *Haematostereum sanguinolentum*)	Stem and log decay	(19)
	Thanatephorus cucumeris (Imperfect stage: *Rhizoctonia solani*)	Damping off	(7)
TECTONA GRANDIS	*Armillaria mellea* s.l.	Root rot	(20)
	Cephaleuros sp. (algae fungus)	Leaf spot	(6)
	Fusarium semitectum	Root	(22)
	Fusarium solani	Canker, wood pink stain.	(23)
	Helicobasidium compactum	Violet root rot	(22)
	Nectria haematococca	Stem canker in nurseries	(6)
	Poria sp.	Root rot	(22)
	Rhizoctonia sp.	Root	(6)
	Ustulina deusta	Stem	(22)
TERMINALIA CATAPPA	*Cercospora catappae*	Leaf spot	(6)
TERMINALIA IVORENSIS	*Mycosphaerella* sp.	Leaf blotch	(6)
THEOBROMA CACAO	*Calonectria rigidiuscula*		(6)
(Imperfect state:	*Fusarium decemcellulare*)	Dieback	(6)
	Cercospora sp.	Leaf spot	(6)
	Fusarium solani	Roots	(6)
	Phomopsis folliculicola	Dieback	(6)
TOONA CILIATA	*Pestalotiopsis disseminata*	Stem canker	(6)
	Thyronectria pseudotrichia	Stem necrosis and twig dieback	(6)

[1]) Numbers in parentheses correspond to the numbers given in the list of references to indicate the source of the information. For convenience, only one reference per disease is provided

[2]) Pers. Comm. = Personal Communication

CONCLUSION

The list of diseases presented in Tables 1 and 2 shows the existence of indigenous and exotic pathogens which can cause severe damage to trees. Some pathogens are capable of attacking more than one host species and may therefore be difficult to control. The list also shows that only 36 indigenous and 45 exotic tree species have been covered so far. However, owing to the fact that Tanzania has a vast forest area and an enormous species diversity, it is justifiable to speculate that there must be many more diseases attacking more tree species than are presented in this report. Moreover, the tables report more diseases of exotic trees than those of indigenous trees although indigenous species in the country are far more numerous than exotic species. The reason for this is that in the past the emphasis was on exotic trees as timber supplements of the indigenous forest trees and also because many of the exotics are grown as plantation and ornamental trees in areas that are easily accessible to foresters and researchers.

Outbreaks have also been significant and severe. Consequently, future prevention of such epidemics should be given priority in forest management programmes. Some initiatives to address the problems through promoting resistance in susceptible species can be taken. For example, some pioneer research was carried out to select resistant genotypes of *P. radiata* against the *Dothistroma* blight (Ivory & Paterson 1970). Although this work was not continued, due to the paucity of experts and other resources which faced forest disease research, it was a good starting-point towards the revival of the conifer in East Africa.

Successful results in research on breeding for disease resistance in some susceptible species in other parts of the world have added impetus to tree breeding. For example, in New Zealand clones of *Pinus radiata* resistant to the *Dothistroma* needle blight are already under development through gradual selection for healthy trees (Ivory & Speight 1993). In the USA it was possible to establish resistant varieties of chestnut trees (*Castanea dentata*) through hybridization of the native survivors of the chestnut blight fungus, *Endothia parasitica* syn. *Cryphonectria parasitica* with the more resistant members of the genus from Europe and Asia (Beattie & Driller 1954). This means that tree breeding in Tanzania can also make use of the common hybridization principles used in tree improvement in order to establish disease resistant forests.

An effort has also been taken to investigate how silvicultural and cultural methods in forest management could limit disease incidence. For example, trials of *O. usambarensis* were established in natural forests of the Usambara and Kilimanjaro mountains in the late 1950s to determine the best treatments in regenerating the species in order to reduce the incidence of transmitting the heart rot of stem and butt to the next regeneration (Kimaryo 1972; Mugasha 1978). Again, owing to lack of forest disease experts and other research resources, this research has had to be abandoned. As a result of insufficient research projects, there has been a stagnation in knowledge on forest diseases and the subsequent efforts to control them. Given that resources were available, possible areas of emphasis would be to carry out more surveys covering all forest types; to study how breeding techniques can be used to develop resistance in susceptible species; to study the effect of diseases on the regeneration capacity of forests; to study the ecological factors and management techniques that might limit the establishment and spread of disease; and to study the effect of diseases on wood quality. Such studies will provide information which

will help forest managers to include certain measures in the protection of forests against potential diseases when formulating management programmes.

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First registration of the cherry fruit fly, *Rhagoletis cerasi* (L.) in western Norway; distribution, size and origin of the population

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The cherry fruit fly, *Rhagoletis cerasi* (L.), a serious pest of sweet cherries, was recorded in Hardanger, western Norway, for the first time in 1991. An investigation was carried out in 1992 and 1993 to register the distribution and the population size of this pest in western and southern Norway. Two geographically separated populations were found in western Norway, one in Sogndal and the other in the Hardanger and Voss region. These populations were found to be geographically discontinuous with a previously known population in southeastern Norway. The population size of the cherry fruit fly was higher in southern than in western Norway. More flies were found and the infestation level of the flies was higher on *Lonicera* bushes than on sweet cherries in western Norway. A crossing experiment was carried out in order to elucidate the subspecific status of the Norwegian populations. It was found that both the western and the southeastern populations belong to the northern race of the cherry fruit fly, but the origin of the western population is uncertain.

Key words: Distribution, *Lonicera*, population size, races, *R. cerasi*, sweet cherries, unidirectional incompatibility.

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The cherry fruit fly, *Rhagoletis cerasi* (L.), is one of the main pests on sweet cherries in central and southern Europe (Boller et al. 1980). Damage is caused by the adult females laying their eggs in the half-ripened sweet cherry fruits, so that the larvae can develop inside the fruits. One female lays an average of 200 eggs, usually one egg in each fruit (Boller & Prokopy 1976). *R. cerasi* is oligophagous and accepts sweet cherries and some species of *Lonicera*, most frequently *L. tartarica* and *L. xylosteum*, as host plants for egg-laying (Katsoyannos et al. 1986). For the adult fly to be active, with respect to mating and egglaying, temperatures have to exceed 16 ^{0}C (Boller 1966).

The cherry fruit fly is distributed throughout most of Europe and in a few regions in Asia (C.A.B. 1989). In Norway, Ausland (1951) reported on a rather large population of

the cherry fruit fly in southern and eastern Norway in the 1930s and 1940s, but this population declined and probably became extinct (Edland 1990). In Hardanger in western Norway fruits of sweet cherry and *Lonicera* have been investigated by the Community Fruit Adviser, Tomas Sekse, from the 1950s up to the 1970s in order to record whether larvae of *R. cerasi* were present. Samples were taken from the fruit-growing areas in this region, but no larvae of *R. cerasi* were found. Occasionally, however, Lepidopterous larvae were found in fruits (Sekse 1992, pers comm.). In 1991 larvae of *R. cerasi* were found in fruits of both *Lonicera* and sweet cherries in three different locations in Sørfjorden, Ullensvang municipality in the Hardanger region (Hesjedal & Jaastad 1993), where approximately 80% of the sweet cherry production in Norway is located.

There are two different races of *R. cerasi*, known as the northern and the southern races. The border between them runs through Germany, France, Austria and Hungary (Boller et al. 1976). A unidirectional incompatibility exists between the races, in that crosses between females of the northern race and males of the southern race are sterile, whereas the reciprocal crosses are fertile (Boller & Bush 1974). This one-way incompatibility makes it possible to elucidate which race is present in an area if crossed with flies of known origin.

The aim of this investigation was to record the distribution and abundance of the cherry fruit fly in Norway. In addition, the origin of the population in western Norway, probably introduced in recent years, was investigated by a crossing experiment.

MATERIAL AND METHODS

Registration of the cherry fruit fly

In 1991 no systematic registration of the cherry fruit fly was carried out, but larvae of the species were found in August in fruits of sweet cherry and *Lonicera* at three different locations, within a 3-km-wide area on the eastern side of Sørfjorden in Hardanger, Hordaland county.

In 1992 yellow traps (Rebell), developed for monitoring and catching *R. cerasi* (Remund & Boller 1978; 1979), were set out in those areas where larvae were found in 1991 (one trap per 10-20 sweet cherry trees). In surrounding areas, covering six municipalities in the Hardanger region, the same ratio of traps to trees was used on one to three farms in every village (Fig. 1). The traps were emptied weekly from mid-June until mid-August. At the end of July 1992 two traps were placed in Sogndal in Sogn and Fjordane county (Fig. 1), after larvae of the cherry fruit fly had been detected in a sweet cherry orchard earlier that year.

In 1993 traps were distributed in all sweet cherry orchards in the Hardanger region (one trap per 10-20 sweet cherry trees). In addition, traps were placed in several municipalities of Sogn and Fjordane, Rogaland, Vest-Agder and Aust-Agder counties (Fig. 1). The traps, which totalled just over 4000 this year, were checked and the flies removed twice, in late June and in mid-July.

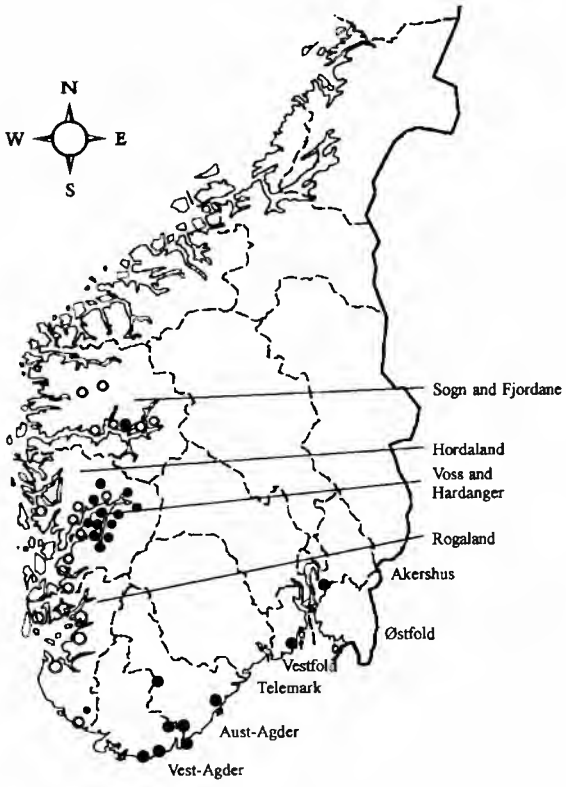

Fig. 1. Distribution of *Rhagoletis cerasi* in Norway. Registrations are based on recordings from yellow traps and from fruit samples of sweet cherry and *Lonicera* fruits. ○ = no flies registered, ● = flies are present

In both 1992 and 1993 samples of fruits were collected from every location where flies were trapped to evaluate the infestation level. In addition, samples of fruits of *Lonicera spp.* were collected at five locations in Bergen and at three locations in Voss in 1993. The fruits were submerged in water to make the larvae emerge, or placed on sand for the larvae to pupate. The number of larvae was then easily counted.

As traps were checked weekly in 1992, data from this year give the best approximate picture of the life cycle of the cherry fruit fly in Hardanger (Fig. 2). The life cycle description is based on data from the whole area, collected from both sweet cherries and *Lonicera* bushes with traps and also in fruit samples. Most pupae were defined to have hatched when there was a peak in the number of adult flies caught. Furthermore, the presence of the first and last larvae was calculated from the first and last egg found, and the known duration of larval development (Ausland 1951).

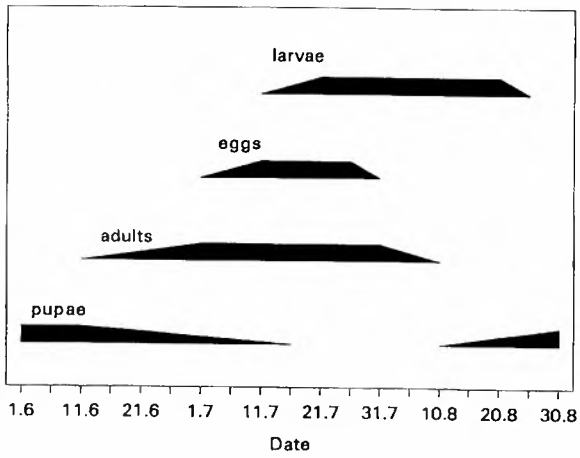

Fig. 2. A rough description of the life cycle of *Rhagoletis cerasi* in Hardanger, based on data collected from *Lonicera* and sweet cherry by traps and fruit samples in 1992

In the municipalities of Ullensvang, Eidfjord, Odda and Ulvik all the sweet cherry trees, in areas where *R. cerasi* was recorded, were sprayed with insecticides against the cherry fruit fly in both 1992 and 1993. All *Lonicera* plants that were registered in the region were also sprayed. Insecticides used were fenthion (Lebaycid) or dimethoate (Rogor L20). In southern- and eastern Norway no insecticides were used, with the exception of at one location in Setesdalen.

Temperature and precipitation data were collected from Landvik, southern Norway and Ullensvang, western Norway in 1992 and 1993 in order to compare abundance and infestation level of the cherry fruit fly with climatic data.

Crossing experiment

A crossing experiment was performed in July 1993 at Eidg. Forschungsanstalt Wädenswil, Switzerland, in order to ascertain the subspecific status of cherry fruit flies in western and eastern Norway.

Crosses were made between unmated females and males collected as larvae from different populations. Females from Ås, eastern Norway, were crossed with Swiss males (southern race); females from Hardanger, western Norway, with Swiss males; males from Ås with Swiss females; males from Hardanger with Swiss females; and, finally, as a control, Swiss males and females were crossed (Table 4). No cross between Norwegian males and females was made, owing to shortage of flies. All flies from Norway were collected from *Lonicera*, as the infestation level of sweet cherries in Norway was very low. The Swiss flies were all collected from sweet cherries.

Three females and one male, 3-7 days old, were put in small cages and allowed to mate and oviposit. The cages contained oviposition domes, and food and water according to Boller (1984). Eggs were removed from the backwall of the domes with a fine hairbrush

every second day during the first week, and every third day during the subsequent week. Eggs were incubated on moist, black filter-paper in petri dishes for hatching. The hatching of eggs was controlled every 2 to 3 days until there was no further hatching.

RESULTS

Registration of the cherry fruit fly

Adult flies were detected in yellow-trap catches in Hardanger (Hordaland county) and in Sogndal (Sogn and Fjordane county) in both 1992 and 1993. No flies were found in Rogaland county, except for one individual just across the border near Vest-Agder county (Fig. 1). In the southern part of Norway, flies were detected along the coast from Mandal to Arendal and in Setesdalen (in Vest-Agder and Aust-Agder counties) (Fig. 1). In addition, samples of infested *Lonicera* fruits indicated that the fly was present in Voss (Hordaland county), Ås (Akershus county) and Larvik (Vestfold county) (samples of sweet cherry fruits).

Most flies were found on sweet cherries in southern Norway (Table 1). However, in Odda, Eidfjord and Ulvik, villages in the Hardanger area, the number of flies found was also relatively high (Table 1). In these villages most of the flies detected were found on *Lonicera* plants.

Table 1. Number of yellow traps and number of flies (*Rhagoletis cerasi*) caught in different areas and regions in Norway in 1992 and 1993. The EIS map squares underlined show where flies were detected

Area/region	EIS map square	No. of traps		No. of flies per trap	
		1992	1993	1992	1993
Hordaland:					
Ullensvang, east	33, 41	838	1554	0.2	0.02
Ullensvang, west	33, 41	10	1484	0.2	0.04
Odda	33	10	124	9	1.5
Eidfjord	41	20	205	2.7	3.1
Ulvik	41	62	165	0.5	0.9
Kvam	41, 31	22	54	0	0.06
Granvin	41	22	28	0	0
Jondal	32	7	26	0	0
Sunnhordland	23	-	7	-	0
Sogn and Fjordane	49, 50, 51	2	169	3.5	0.1
Sunnmøre	67, 68	-	22	-	0
Rogaland	23, 13, 14, 7, 3, 4	-	74	-	0.01
Aust-Agder	2, 5	-	59	-	5.1
Vest-Agder	6	-	48	-	19.6

Infestation levels of sweet cherries were low in Hardanger in both 1992 and 1993. A total of 97 samples (of 100 or 50 fruits) of sweet cherries was collected in Hardanger in 1992, and larvae were found in only two samples from two different locations. In one location (Eidfjord) four larvae in 50 fruits were found, and in the other (Ullensvang, west) two larvae in 50 fruits were found. No infestation at all was found in sweet cherries in

Hardanger in 1993, but only a total of 20 samples (of 100 or 50 fruits) was collected. Similarly, a total of 25 samples (of 100 fruits) taken from sweet cherries in the southern part of Norway in 1993 showed no infestation at all, even though samples were taken from locations with a very high number of flies in the traps. In contrast, infestation of *Lonicera* fruits in several locations were high in both years (Tables 2 and 3).

Table 2. Infestation rates of *R. cerasi* larvae (number/100 fruits) on *Lonicera sp.* fruits in some locations in Hardanger in 1992. Locations are presented with UTM references from M 711 maps and EIS map squares

Area	EIS	UTM	date	n	No. of larvae per 100 fruits mean	std
Odda	33	32VLM6264	6.8	30	9.9	7.3
Kinsarvik	33	32VLM7495	4.8	29	5.1	3.2
Eidfjord	41	32VLN9700	7.8	5	4.6	4.6

n = number of samples, each of 100 fruits, std = standard deviation

Table 3. Infestation of *R. cerasi* larvae (number/100 fruits) on *Lonicera sp.* in some locations in Hardanger, one location in Sogndal and one location in Ås 1993. Locations are presented with UTM references from M 711 maps and EIS map squares

Ares	EIS	UTM	date	n	No. of larvae per 100 fruits mean	std
Hardanger						
Odda	33	32VLM6264	23.7-5.8	2	2.8	-
Kinsarvik	33	32VLM7495	27.7-30.8	2	0.02	-
Eidfjord	41	32VLN9495	23.7-5.8	3	32.0	6.4
Ulvik	41	32VLN8616	19.7	2	4	-
Voss	41	32VLN6125	10.8	1	6.5	-
Sogndal	50	32VLN9889	29.7	3	35.1	10.0
Ås	28	32VNM9915	12.8	4	4.4	1.6

n = number of samples, size of sample varies from 100 to 940 fruits, std = standard deviation

An approximate life cycle of the cherry fruit fly in Hardanger is preseneted in Fig. 2. Adult flies begin hatching in early June, and most flies have hatched by early July. The adult flies can live for a month. Egg-laying starts at the end of June, and goes on until late July. The first larvae appear in early July, and the latest toward the end of August.

Climatic data, temperature and precipitation from 1992 and 1993 can be seen in Fig. 3 (Ullensvang) and Fig. 4 (Landvik). Temperatures were recorded at 2 p.m., as the egg-laying activity is highest in the middle of the day (Boller 1966). Normal temperatures (averaged over 1961-90) for Ullensvang are 13.8°C in June and 15.0°C in July, whereas for Landvik normal temperatures are 14.7°C for June and 16.2° C for July.

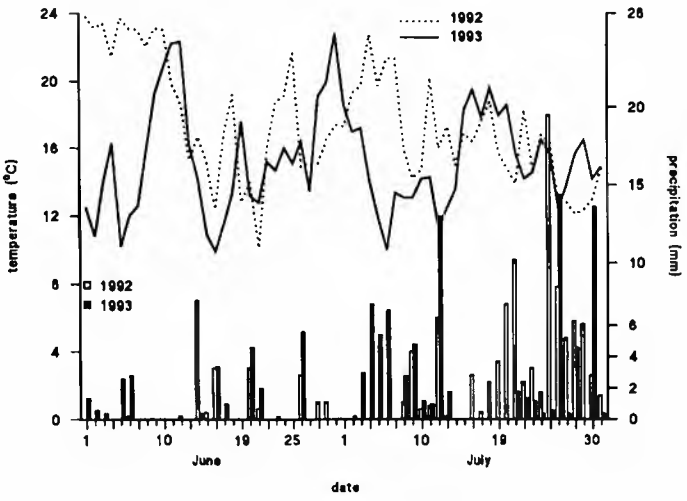

Fig. 3. Climatic data for June and July in Ullensvang, western Norway, in 1992 and 1993. Precipitation is indicated by solid bars, and temperatures measured at 2 p.m. are presented as curves

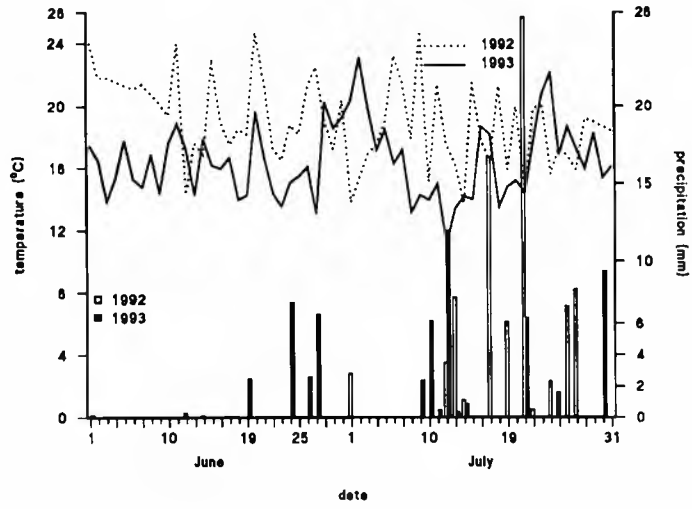

Fig. 4. Climatic data for June and July in Landvik, southern Norway, in 1992 and 1993. Precipitation is indicated by solid bars, and temperatures measured at 2 p.m. are presented as curves

Crossing experiment

Owing to a shortage of flies the number of replicates in each crossing is low. The results clearly show, however, the difference between fertile and sterile crosses. No hatching of eggs was found when Norwegian females were crossed with Swiss males, nor from crossings with females from eastern or from western Norway (Table 4). The proportion of egg hatchings from crossings between Norwegian males and Swiss females, and from crossings between Swiss males and females varied between 0.8 and 0.9. The hatching percentage was low in the first and the last days of egg-laying. One of the crosses between Swiss males and females was excluded from the results because of a sterile male. The number of eggs laid from crossings between Norwegian females (Odda) and Swiss males was low because one female had deformed wings, one had a deformed ovipositor, and one female died after a few days.

Table 4. Results from crossing experiments with Rhagoletis cerasi, presented as the proportion of eggs to be hatched. Flies originating from: Ne = eastern Norway, Nw = western Norway, CH = Switzerland

Crossing	n	No. of eggs laid mean	No. of eggs hatching mean	Proportion hatching mean
Ne♂ x CH♀	2	196.5	176.5	0.893
Nw♂ x CH♀	2	227.5	177	0.81
CH♂ x CH♀	4	538	492	0.904
CH♂ x Ne♀	3	235.7	0	0
CH♂ x Nw[1)]♀	1	288	0	0
CH♂ x Nw[2)]♀	3	78.7	0	0

n = no. of crossings, each between three females and one male
[1)] = flies from Kinsarvik, [2)] flies from Odda

DISCUSSION

As the cherry fruit fly only migrates when there is a lack of oviposition sites, and seldom more than 100 m (Fletcher 1989), we may consider the observed distribution of the cherry fruit fly in Norway as discontinuous. There seem to be two geographically isolated populations in western Norway, one in the Sogndal area (Sogn and Fjordane) and one in the Hardanger and Voss region. In the southern and eastern part of Norway the population seems to be continuous, based on our registrations and the work of Ausland (1951), who reported that in the 1930s and 1940s *R. cerasi* was distributed along the coast from Mandal (Vest-Agder) to Sweden. More flies were found in southern than in western Norway, suggesting a more numerous population of flies in the southern part of the country.

The same year as the cherry fruit fly was first recorded in Hardanger, larvae of the fly were discovered in imported Italian sweet cherries in the same region. Based on this observation, one likely explanation for the existence of *R. cerasi* in Hardanger was that it had been imported with the Italian sweet cherries. Results from the crossing experiments showed, however, that the northern race was present in both western and eastern Norway. Most of the sweet cherries imported to Norway come from regions where the southern race

of the cherry fruit fly is common (Statistisk Sentralbyrå, 1994), and cherries have been imported to Norway since 1955.

In western Norway more flies were found in traps placed on *Lonicera* than on sweet cherries, and the infestation level was higher in *Lonicera* fruits than in sweet cherry fruits. This might indicate that flies have recently switched from *Lonicera* to sweet cherries as a host plant. *Lonicera*, which does not grow naturally in western Norway, is a popular plant in gardens, and has been commonly used since the 1970s, but has also been planted earlier. *Lonicera* was imported to western Norway from Denmark, the Netherlands and southern Norway (nurseries in Hordaland and Rogaland, pers. comm. 1993). Whether or not populations of cherry fruit fly on *Lonicera* and cherries are from two different races has been a matter of controversy (Boller & Prokopy 1976). Boller & Bush (1974) considered populations of *R. cerasi* on *Lonicera* and cherries as two different host races; the development of flies is slower in fruits of *Lonicera* and the hatching period is longer. However, no chromosomatic differences between populations on *Lonicera* and sweet cherries have been found (Bush & Boller 1977), and the two different races are able to reproduce on both host plants, as also confirmed by Ausland (1951).

Since the late 1950s there have been few or no records of *R. cerasi* in southern Norway (Edland 1990). However, in 1991 and 1992 larvae were found in sweet cherries in several locations (Søgne, Mandal, Byglandsfjord) in southern Norway (Regional Fruit Adviser H. Jacobsen 1993, pers. comm.). Fluctuations in the cherry fruit fly populations have been recorded in central Europe, Sweden, Denmark as well as in southern Norway (Ausland 1951; Boller et al. 1970; Ravn & Rasmussen 1994; Rosen 1965). The reason for this is not yet known, but parasites have been proposed as a causal factor (Wiesmann 1943). Edland (1990) argued that birds might have caused the decline (extinction) of *R. cerasi* in southern Norway as many of the cherries were eaten by birds in the course of several years. This seems less likely, however, since birds are probably not particularly efficient cherry-pickers and as many of the trees have been covered with nets against birds. It might be, however, that summer temperatures are responsible for such fluctuations in the *R. cerasi* population, as indicated by Boller (1966). It is likely that summers with low temperatures in the period when fruits are suitably developed for egg-laying, bring about a reduction in the population size. Temperature data from 1993, from both Landvik and Ullensvang, show that in the period when late sweet cherry varieties are suitable for egg-laying (late June/first half of July), the temperatures in the middle of the day were below or only slightly above 16°C. In 1992, however, temperatures were generally higher in both locations. This might explain the lack of infestation of sweet cherries in both western and southern Norway in 1993. The same conclusion has been drawn from an investigation in Denmark in 1993 (Ravn & Rassmussen 1994). Baker (1991) made a model to simulate the activity of *R. cerasi* in England, where the species is not present, based on temperature data in England. He found that the activity of *R. cerasi* would generally be lower in England than in southern Europe, and that there would be a pronounced year to year variation in activity. However, more work is needed to evaluate the effect of temperature as a population-regulating factor. The extensive use of insecticides in the eradication programme on sweet cherries in 1991-93 can partly explain the lack of oviposition in sweet cherries in western Norway in 1992-93. However, as no oviposition was recorded either in southern Norway or in western Norway in 1993, I conclude that the main reason for the lack of

oviposition is the low summer temperature. The difference in summer temperatures between southern and western Norway might also explain the difference in population size between these areas.

In conclusion, the most likely explanation for the occurrence of the cherry fruit fly in western Norway is that it has been imported with *Lonicera* bushes from regions where the northern race of the fly is present. This is supported by the difference in the number of flies (adults and larvae) found on *Lonicera* and sweet cherries in western Norway, as well as the discontinuous distribution making migration from the southern population unlikely. The finding of *R. cerasi* larvae in fruits of *Lonicera* in Voss, where sweet cherry trees are scarce, if present at all, supports this theory. The small population of the cherry fruit fly in western Norway might be attributable to a newly introduced species, or lower summer temperatures in this region causing low egg-laying activity, or to a combination of the two.

Whether the cherry fruit fly can become a major problem for cherry production in western Norway requires more investigation. Further work on correlations between population growth and temperature might give reliable information about the possibility that the cherry fruit fly population can expand to become a serious problem in the sweet cherry-producing areas in Norway.

SUMMARY

After the cherry fruit fly, *Rhagoletis cerasi* (L.), was discovered in 1991 in Hardanger, the main fruit-growing area in Norway, a registration programme was carried out in 1992 and 1993. Registration by yellow traps (Rebell) and samples taken from sweet cherry and *Lonicera* fruits revealed that the cherry fruit fly population in Norway is discontinuous. Two populations seem to exist in western Norway, and one is distributed along the coast of southern Norway. A crossing experiment between Swiss and Norwegian flies revealed that both the western and southern populations in Norway belong to the northern race of the cherry fruit fly. Differences between the amount of flies caught on sweet cherries and *Lonicera* indicate that most probably the populations in western Norway have been imported along with *Lonicera* bushes from areas where the northern race of the fly is present. Summer temperatures might prevent the populations in Norway from expanding.

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Density estimation of soil mineral nitrogen content from farming locations in Norway and from a cropping system experiment

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The variability of soil ammonium and nitrate N (Nmin) content in Norway was investigated by density estimation on both data from farming locations throughout many regions in Norway and data from a cropping system experiment. The main feature of the estimated densities is a positive skewness. The densities based on data from farming locations are most skewed, and some of them have a very long right-hand tail. This is due to the influence of 3-4 observations (of about 100-350 observations) with a very high Nmin content. The difference between spring and autumn values was most marked for data based on farming locations. There seems to be a greater likelihood of high Nmin contents in autumn than in spring. A subsequent test of lognormality of Nmin was generally not rejected and not rejected at all in samples from the cropping system experiment. This suggests that a lognormal distribution gives a good explanation of the variability of Nmin. Therefore an estimate of the mean in the lognormal distribution should give a foundation for advisory services for nitrogen fertilization. Nevertheless, this estimate generally coincides with the arithmetical mean, which at present is used in such advisory services in Norway.

Key words: Density estimation, right-hand skewed distributions, lognormal distribution, mineral nitrogen variability, nitrogen fertilization advisory,

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Optimum levels of nitrogen fertilization vary from year to year, due to differences in nitrogen mineralization, leaching, yield level, and from place to place due to differences in climatic and soil conditions, crop type and crop rotation and previous fertilization, together with interpretations between these factors. Some of the uncertainty in predicting optimum fertilization rates may be removed by taking into account the level of ammonium and nitrate N (Nmin) content available in the soil profile at the start of the growing season (Stabbetorp & Lyngstad 1988, Nielsen & Østergaard 1990). Extensive sampling programmes have therefore been initiated in many countries in order to provide such information (Denmark: Østergaard 1989; Belgium: Vandendriessche et al. 1991; Norway: Riley et al. 1994).

An inherent weakness in the use of Nmin data in such programmes, for both regional and individual recommendations, is their high degree of spatial and temporal variability between fields in a region. Recommendations can be made on a regional basis or for a certain field based on sampling of this field. Normally, the latter method is used except in Denmark. The first method was tested in Holland, but the fertilization error was found to be too large. It is therefore of interest to investigate the stochastic properties of Nmin content between fields in a region. More precisely, we should investigate the distribution of Nmin in fields in a region with regard to 1) main common features across regions in Norway reflecting dissimilarity in soil conditions, crop type, crop rotation and climatic conditions, 2) differences in features (secondary to the main features) by region and crop type, 3) dissimilarity between spring and autumn. The last point is of importance in fertilization recommendations of Nmin, since forecasting of Nmin in spring should be based on measurement of Nmin in autumn. Furthermore, we focus on the degree of similarity between estimated distributions of Nmin based on farming locations and a cropping system experiment.

Such an insight to the distribution of Nmin may be valuable in advisory services for fertilization, by reflecting an underlying distribution of Nmin. Especially, the use of the arithmetical mean of Nmin content for a region to represent a particular situation may be inappropriate if the data display a skewed or otherwise non-normal distribution.

A rough, but not very reliable indication of a distribution may be obtained by using histograms. A more reliable method is that of density estimation (Silverman 1986). This method gives a graphic curve which represents the underlying probability density function. The method itself does not test a hypothesis of any particular distribution, but it may give an indication of which distribution hypothesis to test.

This paper explores the use of this procedure on Nmin data collected in spring and autumn from the topsoil of farming locations throughout many regions of Norway, and in addition on the N content of drainage water samples a cropping system experiment data collected monthly from the Apelsvoll cropping system experiment. A look at histograms of this Nmin data indicates a distribution with a long right-hand tail.

The variability of Nmin from farming locations is influenced by more factors than Nmin from a cropping system experiment. This indicates a greater uncertainty with respect to the estimated density of Nmin based on data from farming locations. Therefore, the purpose of using data from both farming locations and a cropping system experiment is to explore the density estimation to these differences in uncertainty and variability. In this framework we pay attention to common features between the densities from the two data sources. Furthermore, the degree of homogeneity of the densities is explored by these two data sources. The densities from both data sources reflect differences in crops, but the densities based on farming locations reflect in addition more variation in nitrogen fertilization and soil tillage and greater variability in soil and climatic conditions.

The paper contains first a brief description of the method of density estimation. Next, the result of the density estimation from farming locations is presented by regions/crops and the density estimation from the cropping system experiment is presented followed by a discussion in the above mentioned framework of homogeneity/heterogeneity. The accordance of the estimated densities with a lognormal distribution is then discussed. Finally, the result of the density estimation is discussed in relation to mineral nitrogen forecasting and advisory services in nitrogen fertilization.

MATERIALS AND METHODS

The statistical method

Based on samples of observations of Nmin content from farming locations in relatively homogenous regions with regard to crops, soil and climatic conditions, the method of density estimation is used to estimate the underlying Nmin distribution by these homogenous regions. The method is based on independent identically distributed observations. As an example, to give an idea of the feature of the Nmin density, dotplots and histograms of a the sample of Nmin observations from Toten and Hedmark, cereal cultivation in kg/ha in respectively spring and autumn over the period autumn 1989 - spring 94 are presented in fig. 1.

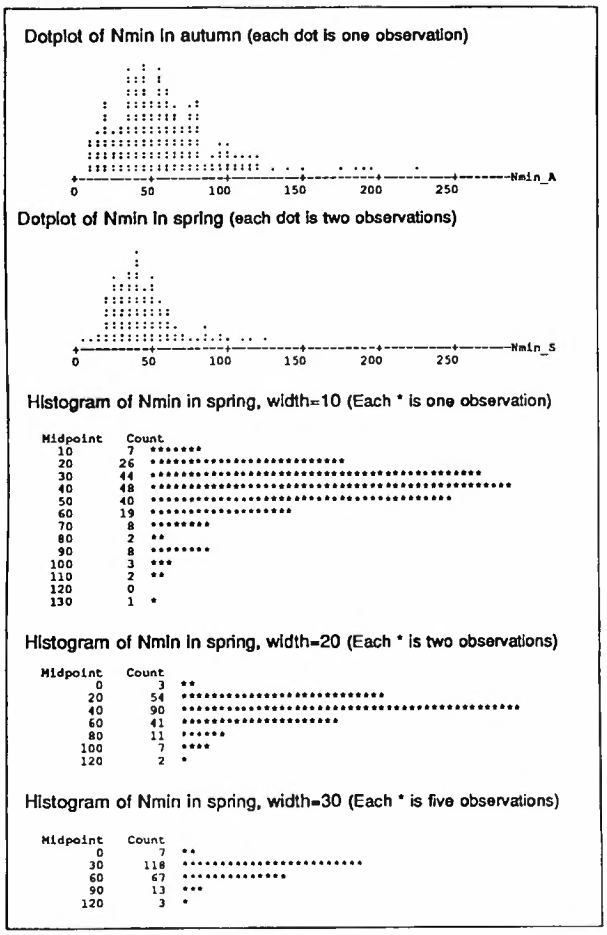

Fig. 1. Nmin content in kg/ha in spring and autumn from farming locations with cereal cultivation in Toten and Hedmark, over the period autumn 1993 - spring 1994. Dotplots and histograms with different bin widths

In this sample, Nmin in kg/ha varied from 8 to 227 in autumn, and from 6 to 126 in spring. Some values were considerably greater than most of the observations, contributing to the long right-hand tail. Dotplots show more detail, while histograms show general form better. However, the feature of the histograms varies with the bin width, entailing problems when estimating the general form of an underlying distribution of Nmin. This is the reason for using density estimation. In a way, the method of density estimation may be comprehended as an advanced histogram, with a criterion for choosing a smoothing parameter (an optimal window with) corresponding to the bin width in a histogram.

Of the various methods for estimating the density function, we have used the adaptive kernel estimator. In this case the method aims to centre kernel functions at the observed Nmin data points with varying window width, reflecting the assumed long right-hand tail of Nmin distribution.

The kernel function K satisfies

$$\int_{-\infty}^{\infty} K(x)\,dx=1 \qquad (1)$$

The adaptive kernel estimator is the sum of the "bumps" placed at Nmin data points.

$$\hat{f}(x) = \frac{1}{n}\sum_{i=1}^{n} \frac{1}{h\lambda_i} K\left(\frac{x-X_i}{h\lambda_i}\right) \qquad (2)$$

In equation (2) 'n' is the sample size, 'Xi' is the i-th Nmin observation, and 'λ_i' is the local window with associated with this Nmin observation. This procedure is based on the common-sence assumption, that it is natural to use a broader kernel in regions of low Nmin density.

The estimator (2) is the result of a two-stage procedure. An initial estimate is used to get a rough idea of the density of Nmin. This estimate yields the pattern of the local window widths corresponding to the various Nmin observations. These window widths are then used to construct the adaptive estimator itself, as formulated in (2). The optimal window with 'h' in (2) follows from minimizing a global measure of discrepancy such as the mean integrated square error. This 'h' depends of the type of kernel function. In this article a normal kernel function is used. Then the optimal 'h' would be $h_{opt} = 1.06*\sigma n^{-1/5}$. See (Silverman 1986) for details about deduction of h_{opt}, and also for the general theory about density estimation.

The framework of estimation of soil mineral nitrogen content

Norway is relatively heterogeneous with regards to soil conditions, aerial environment, etc. These factors and the type of crops and cropping systems influence the level and the variability of Nmin. For this reason nitrogen fertilization advice is given by region (usually by county), where each region is assumed to be relatively homogenous concerning these factors. This should be reflected in the density estimation by estimating the density of Nmin based on farming locations, which are as homogenous as possible with regard to crops and

soil and climatic conditions. There is also a methodical reason for doing this, since density estimation is based on independent, identically distributed observations. Samples of Nmin content in spring (April) and autumn (October) are available from both the whole profile (0-60cm) and the topsoil (0-25cm) from farming locations throughout many regions in Norway. They are stored in the database of the nitrogen prognosis project coordinated by Apelsvoll Research station. Together with the Nmin observations, there are corresponding observations of crop type, soil conditions, soil tillage, fertilization etc. These observations are for most locations available from spring 1989. On aim of this project is to forecast Nmin content in spring based on measured Nmin content in autumn. Knowledge about this relation could then be used in fertilization advisory services. To estimate the underlying probability density function of Nmin content, samples of Nmin measurements in the whole profile in spring and autumn from farming locations throughout some regions/crops are used. For more information about this database, see Abrahmsen (1993).

The above mentioned assumptions of independent identically distributed observations are approximately achieved by focusing on homogeneity in the cross-sectional sample of farming locations in a region, concerning the factors that are assumed to influence the Nmin content (crop, soil and climatic conditions). On the basis of these restrictions and advices received from soil researches, the density estimation of Nmin content in the whole profile for the most important crop in some regions in Norway is performed for spring and autumn respectively. A geographical survey of those regions is given in fig. 2.

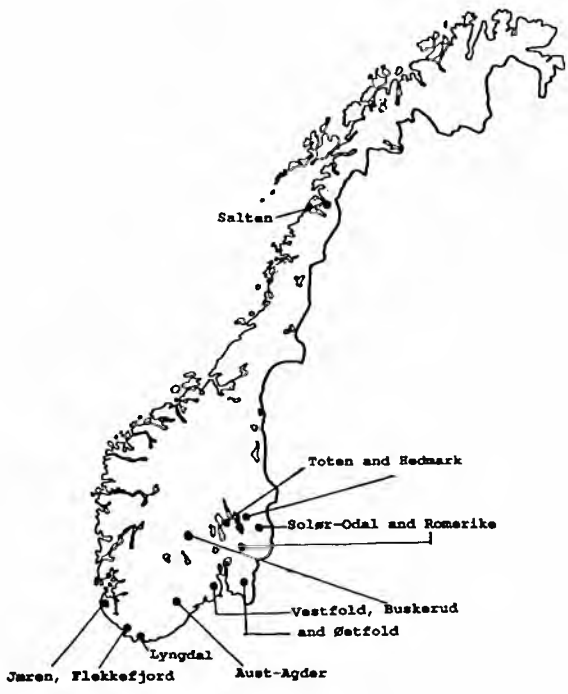

Fig. 2. The regions used for the density estimation, indicating the dominant crop in each area

In addition probability estimates were performed of Nmin in the topsoil (0 - 25 cm) and for respectively nitrate and ammonium content in the whole profile (0 - 60 cm). These densities are not presented, but some comments are then given.

As mentioned above, the Nmin content based on data from farming locations is influenced by many factors. Therefore, it should be of interest to compare the feature of these estimates with density estimates of Nmin based on a cropping system experiment, for example the one located at the Apelsvoll Research Station, which is naturally more homogenous concerning the factors which influence the Nmin content. The database of this project contains monthly observations of drainage water content and total leaching of Nitrogen and other nutrients for some chosen cropping systems reflecting differences in fertilization, soil tillage and crop rotation. See (Eltun 1994). Based on observations from this experiment, the density of Nmin is performed for respectively cash crop farming without farmyard manure and forage crop production with some farmyard manure. Compared with the estimates from the farming locations, these estimates are based on constant soil, topographical and climatic conditions. For this reason, we expect a longer right-hand tail in the estimates based on data from farming locations than in the estimates based on the cropping system experiment.

RESULTS AND DISCUSSION

Estimation of the probability densities

The estimates of Nmin content based on samples from farming locations for the above mentioned regions/crops, and the estimates of N-content of two different cropping systems based on samples from the Apelsvoll cropping system experiment are given in figs. 3 and 4. Some statistics based on these samples used in density estimation are given in tables 1 and 2.

The test of lognormality on 5% level was rejected. For some regions/crops with very high skewness together with rejecting a hypothesis of lognormality, a test of lognormality was performed excluding some few very extreme values. The purpose was to investigate whether the hypothesis of lognormality was still rejected.

The statistics of farming locations in table 1 show that the mean is greater than the median for all regions/crops, and that the skewness is generally great. This comes out especially strongly in Østfold, Buskerud, Vestfold and Aust-Agder. Furthermore, for the three cereal regions and for vegatable cultivation in Aust-Agder this difference between the mean and the median is greater in autumn than in spring. For the two forage crop production regions, the difference is about the same. This difference between autumn and spring is also the same for skewness with the exception of Aust-Agder. These sample statistics indicate for all regions/crops a distribution with a long right-hand tail, which comes out more strongly in autumn than in spring for cereal cultivation.

Compared with the farming locations, the statistics of the cropping system experiment in table 2 generally entail a smaller difference between the mean and the median and a lower degree of skewness. The main features in the difference between autumn and spring of respectively the mean, the median and the skewness are about the same as for farming locations. This indicates a slightly more symmetrical distibution and with a somewhat shorter right-hand tail than the distribution for the farming locations.

Table 1. Statistics from samples of Nmin content (kg/ha) in the whole profile in spring (Nmin_S), and ditto in autumn (Nmin_A) from the period autumn 1989 - spring 1994 by regions/crops in Norway used in density estimation. The statistics are sample size, mean, median, standard deviation, skewness, max value and 90 % quantile together with a test of lognormality

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% quant.	P<W
Toten and Hedmark, cereals								
Nmin_A	211	59	54	35	1,6	227	102	0,012
Nmin_S	208	44	40	20	1,2	214	70	0,024*
Romerike and Solør, cereals								
Nmin_A	252	43	37	27	3,0	243	68	0,193
Nmin_S	245	38	35	20	1,0	109	66	0,001*
Østfold, Vestfold and Buskerud, cereals								
Nmin_A	344	49	37	52	7,3	684	82	0,104
Nmin_S	334	48	43	34	6,0	424	74	0,112
Aust-Agder, vegetables								
Nmin_A	109	83	52	93	2,5	532	194	0,269
Nmin_S	115	35	27	35	4,8	261	55	0,000*
Nmin_S[1)]	112	30	26	14e	1,4	96	51	0,890
Jæren, Flekkefjord and Lyngdal, forage crop pr.								
Nmin_A	62	63	48	46	1,9	234	117	0,189
Nmin_S	74	62	47	44	2,1	217	108	0,002*
Nmin_S[2)]	70	53	44	28	1,4	152	96	0,140
Salten, forage crop production								
Nmin_A	84	36	31	24	2,3	143	58	0,569
Nmin_S	82	38	33	25	2,1	144	68	0,351

* means rejecting a hypothesis of lognormal distribution at 5% level.

[1)] exclusive the three greatest values (176, 263 and 261 kg/ha). All the remaining values were lesser than 100 kg/ha.

[2)] exclusive the four greatest values (187, 196, 214 and 217 kg/ha). In descending order the next values were respectively 152, 135, 108, 103 kg/ha, and the remaining values were lesser than 100 kg/ha.

Table 2: Statistics of samples of Nmin content (g/l) in spring (Mars-April) and ditto in autumn (September-November) based on monthly observations from the Apelsvoll cropping system experiment from the period October 1990 - September 1994 used in density estimation. The statistics are sample size, mean, median, standard deviation, skewness, max value and 90 % quantile

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Cash crop production								
Nmin_A	82	15	13	9	1,6	59	25	0,23
Nmin_S	55	12	11	6	1,0	29	11	0,22
Forage crop production								
Nmin_A	82	10	9	8	3,1	59	9	0,56
Nmin_S	55	11	10	7	1,3	34	10	0,22

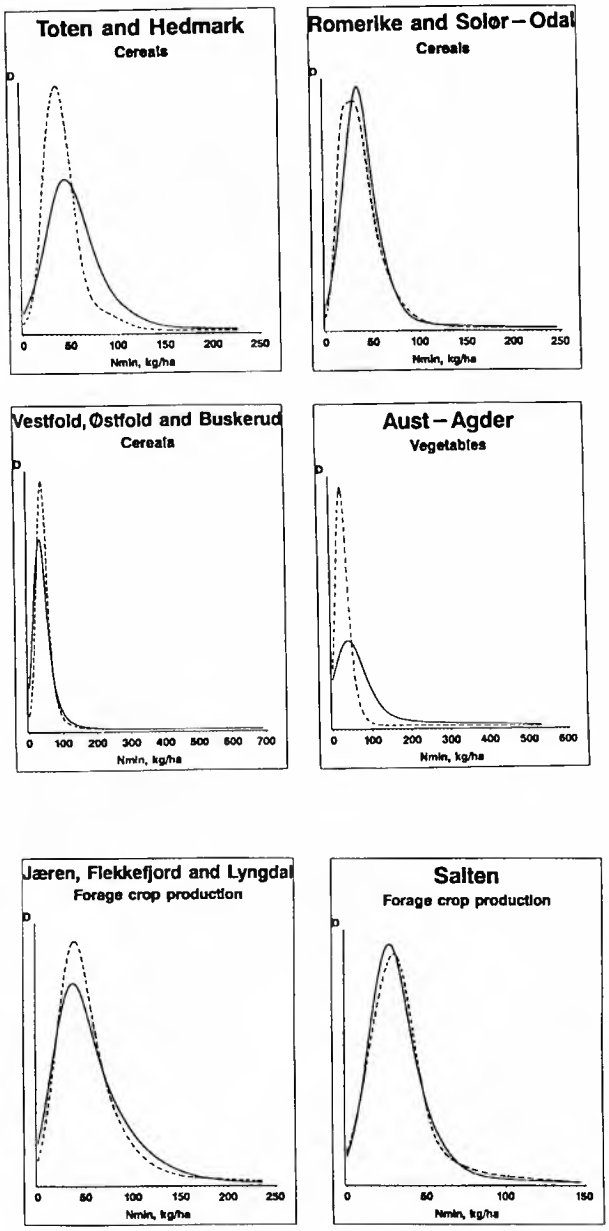

Fig. 3. Estimated densities of Nmin content (kg/ha) in the the whole profie (0 - 60 cm) in spring (April), and ditto in autumn (September) by regions and crops based on data from farming locations from the period spring 1989 - spring 1993. The whole drawn curve is autumn, and the dotted curve spring

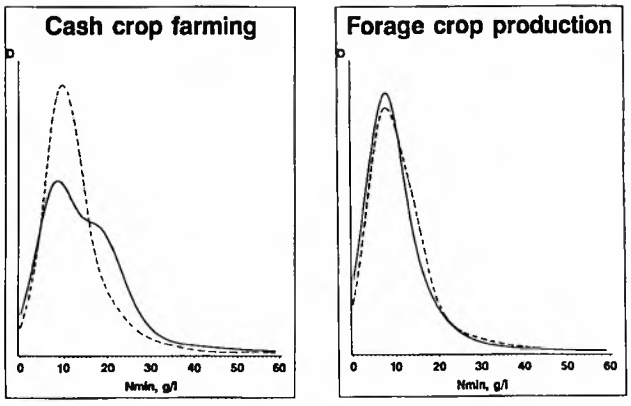

Fig. 4. Estimated densities of N concentration (μg/l) in spring (March-April) and ditto in autumn (September-November) by cropping systems based on monthly observations from the Apelsvoll cropping system experiment from the period October 1990 - September 1994. The whole drawn curve is autumn, and the dotted curve spring

Comments of the estimated densities

The main feature of the estimated densities based on farming locations is a positive skewness, and this feature seems relatively stable for all regions/crops. Secondary to this main feature, there are some differences between regions/crops. The three cereal regions and the vegetable region Aust-Agder are more positively skewed with a long right hand-tail than the two forage crop production regions. Especially this comes out strongly for cereal cultivation in Vestfold, Østfold and Buskerud. This is due to the influence of a few observations with a very high level of Nmin content (3-4 oservations among 200-350 observations in the cereal regions and 3-4 observations among 110 observations from Aust-Agder). Furthermore, the positive skewness is more marked in autumn than in spring for the three cereal regions, while this relationship seems quite contrary for vegetable cultivation in Aust-Agder. For the two forage crop production regions there seems in that respect to be no difference between spring and autumn.

The explanation of a more positively skewed distribution in autumn than in spring may be due to greater reserves of nitrogen due to residual fertilizer-N in soil and/or the presence of readily decomposable plant residues and mineralization of humus. But the result from vegetable cultivation in Aust-Agder and partly also the result from the two forage crop production regions indicates a mineralization process between autumn and spring, probably in early spring. This may be due to the milder climatic conditions in these regions (Aust-Agder and Jæren, Flekkefjord and Lyngdal). Normally, there are only small amounts of Nmin in autumn following forage crop production. Thus a small accumulation of Nmin in spring may cause an increase.

The densities based on data from the cropping system experiment seem generally to be less positively skewed than the densities based on farming locations. There seems to be

a difference between spring and autumn for cash crop farming (more positively skewed in autumn), but not for forage crop production. It is also worth noting the similarity between the feature of the density of forage crop production from the cropping system experiment and from the two densities from farming locations.

The densities of nitrate and ammonium both based on farming locations and the cropping system experiment were also performed. The estimates appeared about the same with regards to right-hand skewness, but the skewness for ammonium was less marked. The shape of the estimates indicates that a lognormal distribution describes the variability of Nmin. Below we test for this distribution and discuss N-forecasting based on lognormal distributions.

Prediction and forecasting of mineral nitrogen

Advisory services for fertilizer recommendations for a certain crop in a region are usually based on the mean of Nmin from a sample of farming locations in that region. In this respect, the recommendations are valid for all fields in a region with roughly the similar cultivation. Some very high Nmin values may be excluded from the mean. This means that the basis for the guidance does not include values of Nmin in the very long right-hand tail.

A foundation for this type of advisory services should use a distribution of Nmin. Then, we should look for a certain distribution suitable as a model for the variability of Nmin. The estimated densities in figs. 1 and 2 above indicate a lognormal distribution as a strong candidate in that respect.

In tables 1 and 2 above the test of lognormality is performed by testing normality of log Nmin based on the same samples as were used for density estimation. The hypothesis of a lognormal distribution was at 5% level rejected in 4 of 12 cases based on samples from farming locations (table 1), and in no case based on samples from the Apelsvoll cropping system experiment. In two samples, the relatively greater skewness was due to the influence of a few (2-3) observations with a very high level of Nmin (Aust-Agder and Jæren, Flekkefjord and Lyngdal). Even then these observations were excluded, the test of lognormality was not rejected.

The advisory services are based on annual observations. Therefore the statistics and the test of lognormality are performed by year based on the same samples as were used in density estimation. Observations coming for the same year should be more homogeneous, especially since between year climate variability is removed. The drawback however is lower reliability owing to smaller samples. Density estimation was not performed by year due to few observations. The results are presented in tables 3 - 8 below.

Table 3: Toten and Hedmark, cereals. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 - spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1989								
Nmin_A	23	67	58	36	2,0	189	100	0,82
Year 1990								
Nmin_S	22	27	25	14	0,4	51	50	0,10
Nmin_A	47	68	61	34	2,5	227	110	0,88
Year 1991								
Nmin_S	49	47	43	16	1,1	94	67	0,60
Nmin_A	46	65	57	29	1,1	152	111	0,03*
Year 1992								
Nmin_S	46	47	44	21	1,3	115	82	0,78
Nmin_A	51	72	60	36	1,9	193	104	0,13
Year 1993								
Nmin_S	50	46	41	19	1,2	97	77	0,11
Nmin_A	44	24	22	11	1,2	60	38	0,55
Year 1994								
Nmin_S	41	42	33	25	1,7	126	70	0,11

* means rejecting a hypothesis of lognormal distribution on 5% level.

Table 4. Romerike and Solør-Odal, cereals. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 - spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1989								
Nmin_A	13	37	34	16	0,9	69	61	0,86
Year 1990								
Nmin_S	12	43	41	11	0,7	65	60	0,90
Nmin_A	45	53	48	20	2,0	133	72	0,05
Year 1991								
Nmin_S	47	49	45	16	1,1	98	76	0,26
Nmin_A	63	47	38	29	3,1	181	68	0,00*
Nmin_A[1)]	61	42	36	18	2,1	127	63	0,18
Year 1992								
Nmin_S	60	45	43	26	0,6	109	82	0,01*
Nmin_A	72	52	44	32	3,6	243	80	0,15
Year 1993								
Nmin_S	72	34	31	18	1,0	87	58	0,06
Nmin_A	59	21	19	9	1,0	43	36	0,24
Year 1994								
Nmin_S	54	25	25	8	0,5	46	37	0,39

* means rejecting a hypothesis of lognormal distribution on 5% level.

[1)] exlusive the two greatest values (181 and 161 kg/ha). In descending order the next one was 127 kg/ha, and the remaining values were lesser than 100 kg/ha.

Table 5. Østfold, Vestfold and Buskerud, cereals. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 - spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1989								
Nmin_A	46	36	58	32	1,3	93	63	0,75
Year 1990								
Nmin_S	45	41	31	60	6,2	424	52	0,00*
Nmin_S[1)]	44	32	31	14	1,8	91	51	0,21
Nmin_A	57	61	43	67	4,1	434	97	0,00*
Nmin_A[2)]	55	50	41	32	2,6	192	75	0,03*
Year 1991								
Nmin_S	42	56	55	24	0,3	117	82	0,01*
Nmin_A	76	56	42	78	7,2	684	85	0,00*
Nmin_A[3)]	75	47	42	27	1,5	161	82	0,28
Year 1992								
Nmin_S	82	38	32	22	2,8	156	58	0,19
Nmin_A	83	60	50	35	1,6	207	110	0,75
Year 1993								
Nmin_S	83	58	53	29	2,9	230	85	0,34
Nmin_A	82	30	25	21	2,8	146	50	0,67
Year 1994								
Nmin_S	82	47	44	29	7,3	288	63	0,00*
Nmin_S[4)]	81	46	44	11	0,7	75	59	0,38

* means rejecting a hypothesis of lognormal distribution on 5% level.

1) exclusive the greatest values (424 kg/ha). All the remaining values were lesser than 100 kg/ha).

2) exclusive the two greatest values (434 and 286 kg/ha). In descending order the values were respectively 192, 151 and 133, and the remaining values were lesser than 100 kg/ha.

3) exclusive the two greatest values (684 kg/ha). In descending order the values were respectively 161, 123, 107 and 103, and the remaining values were lesser than 100 kg/ha.

4) exclusive the greatest values (288 kg/ha). All the remaining values were lesser than 100 kg/ha).

As a main feature, Nmin by year in tables 3 - 8 also seem to be positivly skewed, but in some cases this skewness is relatively small. The differences in Nmin between regions/crops seem on the whole to be the same by year as for the whole period. Nmin is most positively skewed for Østfold, Vestfold and Buskerud. For the two cereal regions Toten and Hedmark and Romerike and Solør-Odal, the skewness by year is more marked in autumn than in spring. This relationship by year is contrary or about the same for the remaining four regions. A hypothesis of lognormality by year is rejected in 10 of 57 cases. However, in some cases a very long right-hand tail due to some few observations entails a too strong skewness for a lognormal distribution. Again, a test of lognormality based on exclusion of these 3-4 observations responsible for the long right-hand tail entailed no rejection of lognormality. In this case a hypothesis of lognormality was rejected only in 4 of 57 cases. In the Apelsvoll cropping system experiment, the hypothesis of lognormality was not rejected at all.

Table 6. Aust-Agder, vegetable cultivation. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 - spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1989								
Nmin_A	17	135	84	146	1,8	533	385	0,70
Year 1990								
Nmin_S	17	44	33	39	2,8	177	66	0,84
Nmin_A	15	30	32	11	0,8	59	41	0,37
Year 1991								
Nmin_S	15	26	25	7	0,5	39	36	0,57
Nmin_A	31	77	53	75	2,3	329	125	0,15
Year 1992								
Nmin_S	32	40	30	43	4,7	261	57	0,01*
Nmin_S[1)]	31	33	29	14	0,8	68	55	0,74
Nmin_A	24	75	52	80	3,2	402	143	0,58
Year 1993								
Nmin_S	27	43	30	42	4,2	239	52	0,01*
Nmin_S[2)]	26	35	30	16	2,4	96	52	0,40
Nmin_A	22	93	68	94	1,5	345	254	0,08
Year 1994								
Nmin_S	24	20	18	9	1,9	51	32	0,78

* means rejecting a hypothesis of lognormal distribution on 5% level.

[1)] exclusive the greatest values (261 kg/ha). All the remaining values were lesser than 100 kg/ha).

[2)] exclusive the greatest values (239 kg/ha). All the remaining values were lesser than 100 kg/ha).

The question of exclusion of extreme value Nmin observations depends of the population of farming locations. If an extreme value Nmin observation is not representative for this population, then it should be excluded in calculation of statistics, testing of hypotheses and in density estimation. A coherent evaluation of estimated densities, calculated statistics and tested hypotheses of lognormality based on samples from both farming locations and the cropping system experiment suggests that the lognormal distribution should be a good model to explain the variability of soil mineral nitrogen.

Based on a lognormal distribution of Nmin, the expection of Nmin was estimated from the above used samples of Nmin by regions/crops and year. These estimates entailed small differences compared with the arithmetical means of Nmin presented in the above mentioned tables. These differenses were not greater than 4 kg/ha in any of the samples from farming locations. This also applies, even when some extreme value observations were excluded. Thus the advisory services in nitrogen fertilization may continue to be based on sample arithmetical means, but estimates of the expection in the lognormal distribution seem nevertheless to give a more reliable foundation.

Table 7. Jæren, Flekkefjord and Lyngdal, forage crop production. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 -spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality (no observations for autumn 1991)

	Sample size	Mean	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1989								
Nmin_A	7	148	133	62	0,5	234	233	0,45
Year 1990								
Nmin_S	7	51	59	16	-0,7	70	70	0,25
Nmin_A	15	66	73	27	0,0	116	95	0,13
Year 1991								
Nmin_S	15	71	68	40	1,8	187	108	0,52
Year 1992								
Nmin_S	14	58	43	49	3,1	217	88	0,01*
Nmin_S[1)]	13	46	41	17	1,6	88	70	0,12
Nmin_A	21	49	40	35	2,2	164	78	0,15
Year 1993								
Nmin_S	19	51	40	44	3,2	214	103	0,04*
Nmin_S[2)]	18	41	39	19	2,0	103	66	0,76
Nmin_A	19	45	37	23	1,1	99	92	0,90
Year 1994								
Nmin_S	19	73	58	48	1,2	196	153	0,22

* means rejecting a hypothesis of lognormal distribution on 5% level.

[1)] exclusive the greatest values (217 kg/ha). All the remaining values were lesser than 100 kg/ha).

[2)] exclusive the greatest values (214 kg/ha). The next greatest value was 103, and the remaining values were lesser than 100 kg/ha).

Table 8. Salten, forage crop production. Statistics from samples of Nmin content in spring (Nmin_S) and autumn (Nmin_S) from the period autumn 1989 - spring 1994 by year based on the sample which was used in density estimation (figure 2). Statistics: Sample size, mean, median, standard deviation, skewness, max value and 90 % quantile, together with test of lognormality and estimate of mean in lognormal distribution

	Sample	Mean size	Median	St.dev	Skewness	Max value	90% qant.	P<W
Year 1990								
Nmin_A	14	36	36	10	0,2	56	52	0,34
Year 1991								
Nmin_S	14	36	36	9	0,2	56	21	0,47
Nmin_A	26	41	33	31	2,2	143	83	0,07
Year 1992								
Nmin_S	26	44	36	29	2,1	144	89	0,39
Nmin_A	28	39	30	23	2,0	121	70	0,42
Year 1993								
Nmin_S	25	37	29	32	1,7	131	97	0,55
Nmin_A	13	23	19	15	1,1	55	50	0,89
Year 1994								
Nmin_S	14	28	24	14	1,9	68	44	0,73

* means rejecting a hypothesis of lognormal distribution on 5% level.

CONCLUDING REMARKS

It is well known that soil Nmin has a high degree of spatial and temporal variability. This is due to the fact that Nmin based on farming locations is influenced by many factors, which are constant in a cropping system experiment. This applies to soil, topographical, and climatic conditions, together with greater variation in fertilization and soil tillage. The features of these estimated densities are influenced by these underlying factors and by interactions between them. Nevertheless, the estimated densities by regions/crops seem to indicate a lognormal distribution, and tests of lognormality by regions/crops and year also seem to lead up to this distribution. Furthermore, this is sustained by the estimated densities and tests of lognormality from the Apelsvoll cropping system experiment, which also in a more stable manner seems to lead up to a lognormal distribution. This is in acordance with the above mentioned different degree of influence on Nmin between these two investigations. A source of uncertainty concerning the result from farming locations is also the small samples for some regions/crops and years.

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Effects of cattle slurry and soil compaction on the earthworm population in a silty clay loam soil in central Norway

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The residual effects of six years with soil compaction and different fertilizers on earthworms were studied on a clay soil in central Norway in 1991. The crop was a five year old ley composed of timothy, meadow fescue and red clover. Cattle slurry significantly increased the number of earthworms, especially the number of *Aporrectodea caliginosa*. NPK-fertilizer caused the least biomass and number of earthworms. Cattle slurry stimulated the earthworm activity shown by earthworm casts at soil surface and earthworm channels in the plough layer. The previous six years with soil compaction had caused a little, but significant decrease in number of earthworms, but no significant effect on earthworm biomass. Below the plough layer the lowest number of earthworm channels and highest penetration resistance were found at the compacted plots.

Key words: Earthworms, fertilizer, ley, soil compaction.

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Soil compaction during application of slurry has been found to reduce infiltration rate and decrease the yield of leys (Myhr et al. 1990; Myhr et al. 1992). Positive effects of earthworms on crop growth have been related to increased root growth in earthworm channels, and the physical mixing of soil by earthworms giving a more uniform distribution of residue and nutrients (Logsdon & Linden 1992). Various effects of compaction on earthworm biomass and number have been reported by Aritajat et al. (1977), Boström (1986) and Hansen (1993).

Animal manure will normally increase the earthworm activity and biomass (Edwards & Lofty 1977). In the first Norwegian experiments on effects of different fertilizers on earthworms Uhlen (1953) found that the number of earthworms were higher where animal

manure had been applied. Very high applications of slurry (350-550 tonnes/ha of slurry) have been found harmful and toxic for earthworms (Curry 1976; Cotton & Curry 1980b). Amounts up to about 100-140 tonnes/ha of slurry each year have shown positive effects of manure and slurry on earthworms (Andersen 1980; Cotton & Curry 1980a). Hansen (1993) found that 106 tonnes/ha each year of diluted cattle slurry (50 % slurry, 50 % water) (200 kg N/ha) caused a reduction in earthworm biomass compared to 78 tonnes/ha of diluted cattle slurry each year (150 kg N/ha).

In this investigation the effects of soil compaction and use of inorganic fertilizer or cattle slurry on earthworm population were studied. In 1991, the year when the earthworm investigation was carried out, the residual effects of six years soil compaction and different fertilizers in arable crops and ley were studied.

MATERIALS AND METHODS

Description of the experimental site and experimental plan

A field experiment designed to study the effects of slurry and soil compaction on yields of green fodder and ley (Myhr et al. 1992) was also used to study the treatment effects on the earthworm population. The location was Skjetlein Agricultural School, 15 km south of the city of Trondheim, central Norway. Normal annual precipitation is 832 mm and mean annual air temperature is 4.7°C. The soil was a silty clay loam, poorly drained, with about 30% clay, 65% silt and 5% sand. Organic carbon was 2.5% in the Ap-horizon and 0.3% in the horizon below. The soil was classified as Typic Cryaquept according to Soil Survey Staff (1992).

The experiment started in 1985 and was finished in 1991. The crops were: 1985, green fodder (oats, ryegrass, peas), 1986, spring barley, 1986-1991 ley (timothy, meadow fescue, red clover). The experimental plan was split-plot with soil compaction on great plots and fertilizer treatments on small plots and there were two replicates.

Soil compaction

1. Ordinary traffic with tractor by tillage and harvesting by two-wheel tractor
2. In addition to 1.: Two passes with tractor rear wheel by rear wheel with a tractor of 3.8 tonnes after 1st cut and 2nd cut.

In 1991 no additional soil compaction was applied.

Fertilizer

Control No fertilizer

FS Fresh cattle slurry, 8 % DM. 1985: 80 tonnes/ha in spring + 40 tonnes/ha after 1st cut. 1986: 40 tonnes/ha. 1987-1990: 50 tonnes/ha in spring + 2.5 tonnes/ha after 1st cut. 1991: No slurry.

AS Aerated cattle slurry, 6.4 % DM. 1985: 80 tonnes/ha in spring + 40 tonnes/ha after 1st cut. 1986: 40 tonnes/ha. 1987-1990: 50 tonnes/ha in spring + 2.5 tonnes/ha after 1st cut. 1991: No slurry.

NPK Compound NPK-fertilizer. 1985: 1200 kg/ha (18-3-15) in spring + 600 kg/ha (18-3-15) after 1st cut. 1986: 500 kg/ha (21-4-10). 1987-1990: 700 kg/ha (18-3-15) in spring + 50 kg/ha (18-3-15) after 1st cut. 1991: No fertilizer.

Sampling of earthworms

Soil sampling and sampling of earthworms were carried out after 1st cut in the period 15th July-2nd August 1991. Visible worm casts at soil surface were counted on squares of 0.25 m^2. Observations were carried out at two squares per plot, and the earthworms were sampled by handsorting (Nordström & Rundgren 1972). The soil was divided into layers 0-10, 10-25 and 25-40 cm. The soil was dug by a flat spade, broken up by hand and the worms were collected. The worms were grouped into three groups based on identification in field: *Aporrectodea caliginosa/Aporrectodea longa*, *Aporrectodea rosea*, and *Lumbricus rubellus/Lumbricus terrestris*. Typical specimens of the different species were preserved with formaldehyde for identification. The worms in the different groups were weighed and counted the same day as they were collected.

Worm channels were counted at horizontal sections at 10, 25 and 40 cm depth. Penetration resistance was recorded by a pocket penetrometer (Eijkelkamp WF 24980) at horizontal sections of 10, 25 and 40 cm depth. Ten individual measurements per horizontal section were carried out. The maximum recording level for this penetrometer was 2900 kPa. Higher values were recorded as 3000 kPa.

Statistical methods

Two way analysis of variance was carried out with the procedure ANOVA (SAS Institute 1987). The interaction replicate*compaction was used as an error term to test the effect of compaction. Student-Newman-Keuls (SNK) test with $\alpha=0.05$ was used for the fertilization treatments.

RESULTS

Number and biomass of earthworms

Five different species were recorded: *Aporrectodea caliginosa* (Savigny), *Aporrectodea rosea* (Savigny), *Aporrectodea longa* Ude, *Lumbricus rubellus* (Hoffmeister) and *Lumbricus terrestris* L. The dominant species was *A. caliginosa*. Only a few adults of *A. longa* and *L. terrestris* were found.

Slurry (FS and AS) gave the highest number of earthworms/m^2. There was significantly less earthworms at the control treatment than at the FS treatment, and least earthworms at the NPK-treatment (Figure 1). The differences in biomass between the treatments were not significant.

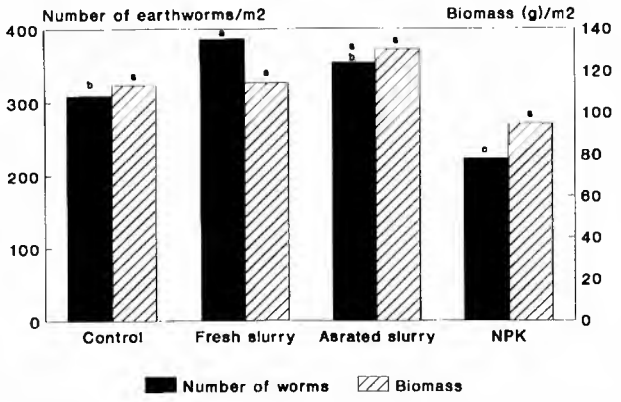

Figure 1. Number and biomass (g) of earthworms/m^2 after different fertilizer treatments. Treatments with same letter are not significantly different ($P > 0.05$)

In the layer 0-10 cm there was no significant differences in total earthworm biomass and total number of earthworms between the treatments (Figure 2a and b). However, in this layer the highest number of the *Aporrectodea* species was found on the FS treatment, while the highest number of the *Lumbricus* species was found on the control treatment. The NPK treatment had significantly lowest number of earthworms both for *Aporrectodea* and *Lumbricus* species (Table 1). The number of earthworms and earthworm biomass were significantly higher for the AS treatment in the layer 10-25 cm than the other treatments (Figure 2a and 2b). In this layer both biomass and number of *A. caliginosa/longa* were higher at AS than the other treatments, while the *Lumbricus* species were not significantly influenced (Table 1).

The ratio, number of earthworms to biomass, showed that there were more small (juvenile) earthworms in the layer 0-10 cm than in 10-25 cm (Table 1). This was especially pronounced for *L. rubellus/terrestris* (mean weight: 0.25 g (0-10 cm), 0.82 g (10-25 cm), but clear also for *A. caliginosa/longa* (mean weight: 0.41 g (0-10 cm), 0.61 g (10-25 cm).

Soil compaction significantly decreased the total number of earthworms (Table 2). Although the reduction was greatest in the layer 10-25 cm, this decrease was not significant ($0.05 < P < 0.1$). The biomass of earthworms was not significantly influenced by the compaction (Table 2). *L. rubellus/terrestris* showed a significant increase in number/m^2 after soil compaction in the layer 0-10 cm, but the compaction did not significantly influence the biomass (Table 3). The reduction of number and biomass/m^2 of *A. rosea* in the layer 10-25 cm was significant.

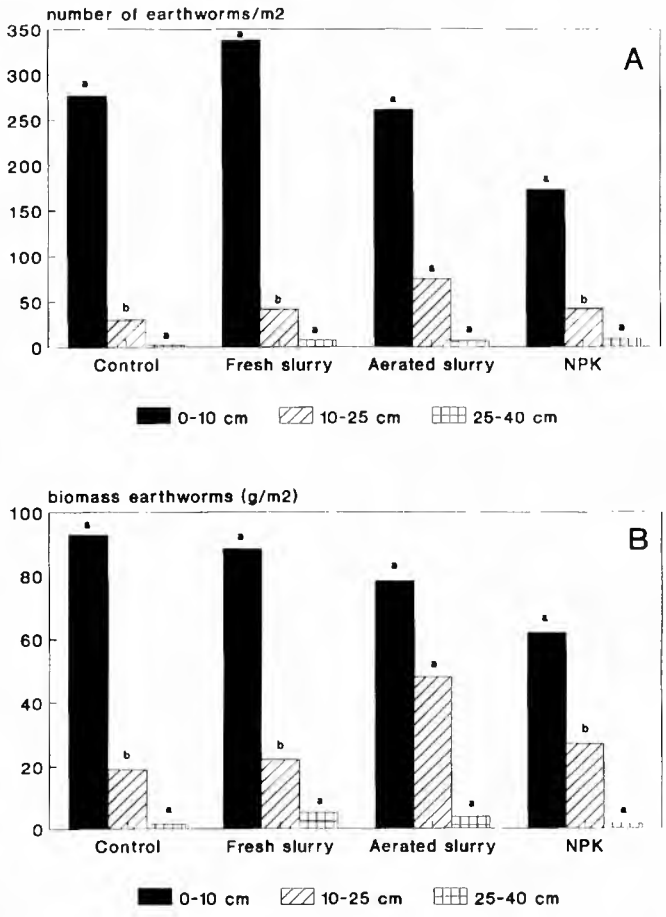

Figure 2. a) Number of earthworms/m^2 in the layers 0-10 cm, 10-25 cm and 25-40 cm after different fertilizer treatments. b) Biomass of earthworms (g/m^2) in the layers 0-10 cm, 10-25 cm and 25-40 cm after different fertilizer treatments. Separate analysis of variance for each layer. Treatments with same letter are not significantly different ($P > 0.05$)

Earthworm casts and channels

There were most earthworm casts at soil surface at the FS treated plots and least at the NPK treatment. There were significantly fewer earthworm casts at the AS treatment than the FS treatment, and significantly more than at the NPK treatment (Figure 3). The number of earthworm casts at the AS and control treatments was about the same. Soil compaction did not influence the earthworm casts.

Highest number of earthworm channels at 10 cm depth was found for the FS treatment, and significantly less earthworm channels at 10 cm for the other treatments (Table 4). There were less earthworm channels at 25 and 40 cm for the treatment with extra compaction (Table 4).

Table 1. Distribution of different earthworm groups (number and biomass) in 0-10 cm and 10-25 cm after six years with different fertilizer use. Separate analysis of variance for each species and layer. Treatments with the same letter are not significantly different ($P > 0.05$)

		Treatment							
		Control		FS		AS		NPK	
A. caliginosa/longa									
0-10 cm	Number/m²	124	b	196	a	144	b	99	b
	Biomass, g/m²	57	a	66	a	58	a	44	a
10-25 cm	Number/m²	24	b	37	b	64	a	36	b
	Biomass, g/m²	15	b	20	b	41	a	23	b
0-40 cm	Number/m²	148	b	240	a	212	a	143	b
total	Biomass, g/m²	73	a	91	a	101	a	73	a
A. rosea									
0-10 cm	Number/m²	54	ab	74	a	49	b	30	b
	Biomass, g/m²	7.6	ab	9.6	a	5.6	ab	3.8	b
10-25 cm	Number/m²	1.6	a	3.0	a	3.0	a	3.5	a
	Biomass, g/m²	0.2	a	0.7	a	0.6	a	1.1	a
0-40 cm	Number/m²	56	ab	77	a	52	ab	34	b
total	Biomass, g/m²	6.3	ab	10.3	a	6.2	ab	4.9	b
L. rubellus/terrestris									
0-10 cm	Number/m²	99	a	69	ab	69	ab	42	b
	Biomass, g/m²	28	a	13	b	14	b	14	b
10-25 cm	Number/m²	5.0	a	1.5	a	8.5	a	2.5	a
	Biomass, g/m²	3.8	a	1.0	a	7.0	a	2.6	a
0-40 cm	Number/m²	106	a	72	ab	79	ab	47	b
total	Biomass, g/m²	33	a	15	b	23	ab	17	b

Table 2. Number and biomass of earthworms per m² after six years with soil compaction

Layer	Comp. 1	Comp. 2	Sign. level	Comp. 1	Comp. 2	Sign. level
	number/m²			Biomass, g/m²		
0-10 cm	248.6	275.0	-	80.5	80.2	-
10-25 cm	70.3	23.8	-	42.8	15.4	-
25-40 cm	7.8	4.6	-	4.8	3.0	-
Total	326.7	303.4	*	128.1	98.6	-

- Not significant
* Significant, $p \leq 0.05$

Table 3. Number and biomass per m^2 of different earthworm species in different layers after six years with soil compaction. Separate analysis of variance for each species and layer

Species/ Layers	Number/m^2 Compaction 1	2	Sign. level	Biomass (g/m^2) Compaction 1	2	Sign. level
A. caliginosa/longa, 0-10 cm	138.0	143.3	-	57.3	55.2	-
A. caliginosa/longa, 10-25 cm	60.8	19.0	-	36.6	13.0	-
A. caliginosa/longa, 0-40 cm, total	205.5	165.3	-	94.1	68.1	-
A. rosea, 0-10 cm	52.3	50.6	-	6.2	7.1	-
A. rosea, 10-25 cm	4.0	1.5	***	1.0	0.3	*
A. rosea, 0-40 cm, total	56.3	53.3	-	7.2	7.4	-
L. rubellus/terrestris, 0-10 cm	58.5	81.0	*	16.9	17.9	-
L. rubellus/terrestris, 10-25 cm	5.5	3.0	-	5.1	2.1	-
L. rubellus/terrestris, 0-40 cm, total	65.0	86.0	*	22.0	19.9	-

- Not significant
* Significant, $p \leq 0.05$
** Significant, $p \leq 0.01$
*** Significant, $p \leq 0.001$

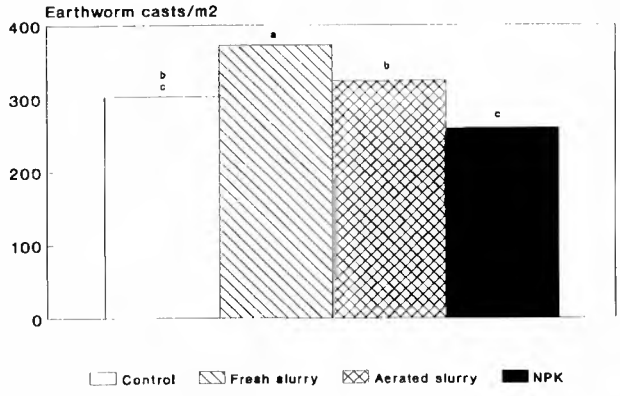

Figure 3. Earthworm casts at soil surface (number/m^2) after use of different fertilizers. Treatments with same letter are not significantly different ($P > 0.05$)

Soil properties

There were no significant differences in penetration resistance between the fertilizer treatments. At 10 cm the mean penetration resistance was 1535 kPa, at 25 cm 2865 kPa and at 40 cm 2763 kPa. There was a tendency of increased penetration resistance at 10, 25 and 40 cm at the compacted treatment (Figure 4), which was not significant. Below the plough layer plant roots were only observed in worm channels.

Table 4. Earthworm channels at different depths (number/m^2) after use of different fertilizers and soil compaction. Treatments with same letter are not significantly different ($P > 0.05$)

Treatment	Earthworms channels/m^2		
	10 cm	25 cm	40 cm
Control	388 b	575 a	523 a
Fresh slurry	492 a	643 a	548 a
Aerated slurry	392 b	578 a	554 a
NPK-fertilizer	360 b	564 a	560 a
Compaction 1	440 a	661 a	599 a
Compaction 2	372 a	518 b	493 b

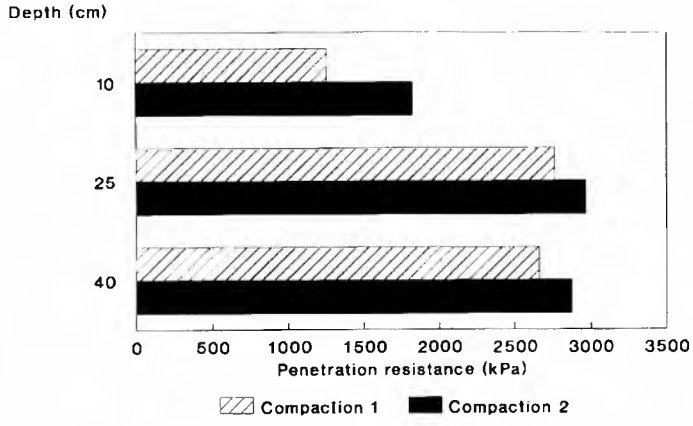

Figure 4. Penetration resistance (kPa) at different depths. Higher values than 2900 kPa are recorded as 3000 kPa

DISCUSSION

The positive effect of cattle slurry on earthworms compared to NPK-fertilizer and control (Figure 1) is consistent with results of Andersen (1980), Andersen (1987) and Hansen (1993). In the investigation of Andersen (1980) the number and biomass of *Aporrectodea caliginosa* especially increased in the slurry treatments, while *Aporrectodea longa* increased in the farmyard manure treatments. In rehabilitating mined land Scullion & Ramshaw (1987) found that topdressed poultry manure positively influenced *A. caliginosa* at mined land and *L. terrestris* at undisturbed soil. In another experiment with *L. rubellus/festivus* and *Allolobophora chlorotica* present, only number of *L. rubellus/festivus* were increased by poultry manure. At Skjetlein the slurry treatments significantly increased the number of *A. caliginosa*. Since *A. caliginosa* is a consumer of humus, the increase of this species may fit well with a soil where growth of bacteria and other microorganisms has been stimulated after the slurry application (Andersen 1980).

The ley at the control had significantly higher clover content than the other treatments during the period 1987-1991 (Larsen 1992). The positive effect of the control treatment on *L. rubellus/terrestris* may be related to the higher clover content.

Fresh slurry and aerated slurry both stimulated *A. caliginosa/longa*, but the ratio, number of earthworms to biomass, was different for the two types of slurry (FS 0.38 g, AS 0.48 g). There were fewer and larger earthworms at the AS treatment than at the FS treatment. The higher number and biomass of earthworms for AS at 10-25 cm depth (mean weight of worms: 0.64 g), show a higher proportion of adults of *A. caliginosa/longa*. Presumedly the different slurry types have caused differences in reproduction rate. Since earthworm cocoons were not recorded and earthworms were not grouped in juveniles, sub-adults and adults for each of the earthworm species in this investigation, only the weight of the earthworms can be used as indication of reproduction rate.

Although soil compaction significantly decreased the total number of earthworms at Skjetlein, the difference in biomass was not significant. At Skjetlein the soil was not compacted in 1991 when the investigation was carried out, but had been compacted the previous six years. The grass yields were reduced in the years when the soil was compacted, but the effect of compaction on grass yield was levelled out in 1991 (Larsen 1991). Hansen (1993) found that soil compaction decreased the number and biomass of earthworms by about 70 % in an experiment with ley on a sandy loam in western Norway. Positive effects of cattle manure and slurry were found in uncompacted soil, but not in compacted soil. Aritajat et al. (1977) found that earthworm population and biomass were not influenced by one time compaction, but halved due to ten times soil compaction six months after compaction in a clay soil. However, the differences were not statistically significant. On a silt loam soil ten times compaction significantly decreased biomass of earthworms four months after treatment, and 10 months after soil compaction the number of earthworms at the ten times compacted treatment was still significantly less than at the control. Also in this experiment one time compaction did not significantly reduce the earthworm population. The minor effect of compaction on earthworms at Skjetlein may be due a recovery of the population after compaction. The high number of earthworms, especially *Lumbricus* species, in 0-10 cm depth (Table 3), indicate increased reproduction of this group of earthworms after compaction. Compared to the ten times compaction treatment of Aritajat et al. (1977) the highest compaction level at Skjetlein was moderate, and close to normal compaction by agricultural machinery with two cuts in grassland.

The slurry treatments increased the amount of earthworm casts at Skjetlein (Figure 3). Similar results were found by Scullion & Ramshaw (1987) where topdressed poultry manure increased surface casting, and NPK fertilizer reduced casting. *A. caliginosa*, which was the dominant species at Skjetlein, has been reported to make large numbers of casts (Lee 1985).

There were many earthworm channels in the plough layer (360-492/m^2) and below the plough layer (564-643/m^2). According to Lee (1985) 100-800 earthworm channels per m^2 in horizontal sections have been found in different soils with different agricultural practices. The significant effect of fresh slurry on earthworm channels in the plough layer coincided with a high number of earthworm casts (Figures 1 and 3). The negative effect of compaction on earthworm channels below the plough layer was more surprising, since there were no significant effects of compaction on the earthworm channels in the plough

layer (Table 4). However, Eriksson (1982) found the plough layer and the upper part of the subsoil to be compacted in a long-term experiment with tractor traffic on clay soil. He found that tractor traffic caused a marked reduction of total porosity, air-filled pores and air-permeability in the plough layer and the upper part of the subsoil compared to the treatment without tractor traffic. At Skjetlein there were higher penetration resistance and lower macroporosity (earthworm channels) below the plough layer at the compacted treatment. More than 80 % of the penetrometer readings at the compacted treatment at 25 cm depth were out of scale (>2900 kPa) and were recorded as 3000 kPa. At the treatment without extra compaction only 25 % of the readings were out of scale at the same depth. The limited scale of the penetrometer probably caused that the difference was not statistically significant.

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Effects of long-term crop rotations, fertilizer, farm manure and straw on soil productivity I. Experimental design and yields of grain, hay and row crops

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The dry matter yields for 1981-1992 in a crop rotation-fertilizer experiment, established in 1954 on clay loam at Ås, Norway, are reported and compared with yield results for the period 1963-80. Four six-course rotations are used: Spring grain only (I); 3-year grain crops and 3-year row crops (II); 4-year grain and 2-year clover-timothy ley (III); 2-year grain and 4-year ley (IV). The crop rotations were in a split block design with four to eight fertilizer rates including the application of farm manure every sixth year, and in arable rotations also yearly ploughed-in straw. The large effect of 2-year ley on grain yield decreased in relation to N fertilizer level, fell off with time distance from the ley period, and was almost absent in the fourth year after 2 years' ley. The after-effects of the fourth year's ley were more long-lasting as evaluated in an additional 4-year period with cereals in the 1970s. The effect of row crops upon subsequent cereals was not consistent. Long-term yield effects of farm manure and straw were small. Additional top dressing with 80 kg N per hectare to spring wheat in the year of ley establishment reduced clover growth without reducing the hay yields.

Key words: Clover-grass ley, expected mean squares, farm manure, grain, row crops, straw.

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A change in the cropping system towards all-arable or all-grain rotations took place in southeastern Norway after World War II. In other districts of the country, especially in high rainfall areas, the practice of continuously growing grasses is common and has become even more prevalent in recent decades.

The effects of crop rotation or lack of rotation, especially in arable cropping, have been a matter of concern in Norway. Historically, the introduction of crop rotation had a favourable effect upon agricultural crop production for more than a century. The effects of one crop species upon the growth of the subsequent crops are complex, and can be

caused by a variety of plant and soil factors.

The short-term previous effects of annual crops can be investigated in relatively simple experiments, whereas the longtime crop-rotation effects of perennial grassland and of repeated crop rotation sequences demand complex and long-term rotation experiments.

The aim of the experiment dealt with here was mainly to investigate possible long-term changes in sustainability of the agricultural system under all arable cropping compared to rotations including perennial grassland. Such long-term effects are associated with changes in the content of organic matter, nitrogen mineralization rates and also with possible deterioration of soil physical properties. Results indicating changes in total-N and total-C over a 30-year period as influenced by leys, N fertilizer, farm manure and straw treatments in this rotation experiment and other long-term experiments are reported by Uhlen (1991). Likewise the effects upon soil aggregation and aggregate stability have recently been investigated by Skøien (1993).

MATERIALS AND EXPERIMENTAL DESIGN

An experiment with four six-course rotations and eight fertilizer treatments was started in 1953 at Ås, Norway on a clay loam high in organic matter. Topsoil samples were taken every six years and analyses in 1984 gave the following average values: Total-C 3.5%, Total-N 0.30%, pH (in H_2O) 5.8, easily soluble P and K (P-AL and K-AL according to Egnér et al. 1960) 12.5 and 11.4 mg per 100 g dry soil respectively. The field was limed twice in the 1970s with 4 tons limestone per hectare, and calcium nitrate as the main N source has also contributed to a relatively low lime requirement.

Organic matter content and clay content were somewhat varyied within the field, the clay content averaging 25% in the topsoil and somewhat more in the subsoil.

The experimental treatments have been subject to some changes during the 40 years: fertilizer rates have been increased in accordance with the common trends in agriculture, and also the crop sequences have been adjusted somewhat, as explained later in this article.

From 1978 to 1992 the following plan has been used:

Crop sequences in the six-course rotations:
Sequence no. = block no. in 1982, 1988

	1	2	3	4	5	6
I	Barley	Spring wheat	Barley	Oats	Spring wheat	Oats
II	Potatoes	Swedes	Barley	Beet	Spring wheat	Oats
III	Barley	Spring wheat*	1st year ley	2nd year ley	Spring wheat	Oats
IV	Barley	Spring wheat*	1st year ley	2nd year ley	3rd year ley	4th year ley

*Timothy and red clover seeded in with the spring wheat.
All crops represented every year and duplicated (= 48 rotation plots) and placed in blocks of four plots.

Fertilizer and manure treatments: (see also Tables 3-8)

a. Moderate rates of N, P and K in fertilizer. Same amounts for rotations I-IV, in the period 1953-80. Later on, rates were differentiated somewhat between crop species.
b. Normal rates of N, P and K fertilizers to different crops.
c. Farm manure 60 t/ha in the year with potatoes and barley (sequence no. 1 above) + NPK in fertilizer commensurate with treatment b.
d. I and II. As for b + all cereal straw ploughed in.
d. III and IV. As for c + additional fertilizer for grassland.

In order to try out higher N rates, half of each of all the grain plots were treated with an additional 80 kg N per hectare after sprouting. Before 1980 the extra N application was 42 kg per hectare. This top dressing of N, in calcium nitrate, was applied alternately on the left- and right-hand side of the subplots. In the first and second ley years half plots were also harvested in order to measure the after-effects of additional N in the year of ley establishment. The harvested subplots per year numbered 240 plots of grain, 40 of grassland harvested twice per year and 32 plots of root crops or potatoes.

The rotation treatments I-IV and the fertilizer treatments a, b and c are of complete factorial design, whereas treatment d is not. Ploughing-in of straw residue has no place in ley farming. The field design is of split blocks, with rotation and fertilizer treatments crosswise on rows or columns, thus affording the highest precision for determining the rotation x fertilizer interactions.

The main comparisons to be made will be within the same blocks and sequence numbers. As can be seen, the effects on cereal yields in the first to the fourth years after a 2-year grass-clover ley are measured in sequence nos. 5, 6, 1 and 2 respectively. Likewise, the effects of a 4-year ley can be found in sequence nos. 1 and 2. In both cases the comparison standard is rotation I. The after-effects of 1 or 2 years of row crops in cereal grain yield will appear in sequence nos. 5 and 3.

Farm manure (FYM) from milking cows was incorporated in spring by harrowing before planting. After 1980 the farm manure was used in the form of slurry, but was relatively high in nutrients. In the 12 years between 1981 and 1992) the average amounts of nutrient applied per ton manure were as follows (kg):

Total-N	NH_4-N	Total-P	K	S	Cl	Ca	Mg	Na
3.9	1.8	0.7	3.4	0.5	1.7	1.3	0.6	0.4

In the plan the N, P and K values of 60 tons FYM were set to 140, 60 and 200 kg respectively. The N, P and K levels in fertilizers applied in treatment c were reduced by these amounts compared to treatment b. This reduction was apportioned over the rotation period, although the largest correction was made for N and K in the year of FYM application. Some additional adjustment had to be made in the year after the FYM treatment based on chemical analysis. For nitrogen, the reduction in N fertilizer over six years in treatment c is greater than the applied 108 kg NH_4-N, but much less than the total-N in FYM (234 kg).

In treatments Id and IId the potassium rate was reduced by 20 kg K per hectare in all

years after ploughing-in the straw. Applications of N, P and K for the different crops and treatments are given in Tables 3-7.

All soil cultivations were done by tractor and ordinary farm equipment, and care was taken to avoid soil transport to neighbouring plots. Only a 2 m x 4.2 m area of the grain plots was combine harvested. For grass plots, a cutter with an automatic balance was used.

From all crops and plots, samples were drawn for dry matter determination. Chemical analyses were performed annually for some of the treatments, and these results will be dealt with in a later publication.

The cereal grain plots were sprayed with weed killers after sprouting, and further spraying against couch grass was carried out on some plots in late autumn. In the last 12 years cultivars of barley, oats and spring wheat were, respectively, Pernilla, Mustang and Runar.

SOME RESULTS OF STATISTICAL ANALYSES

The statistical analyses following SAS guidelines were carried out for yield data from the last 12-year period.

The expected mean yield

$$X_{ijkl} = \mu + B/y_i + r_j + f_k + rxf_{jk} + B/y \times r_{ij} + B/y \times f_{ik} + B/y \times r \times f_{ijk} + Rep_l + E_{ijkl}$$

where B/y are blocks, confounded with years, r = rotations and f = fertilizer treatments. The last error term indicates the yield differences between the two plots with the same treatments, corrected for mean Rep. differences. However, for testing the rotation x fertilizer treatment effects, the appropriate term is $B/y \times r \times f_{ijk}$. This variance can be further divided in block, nos. 1-6, periods, 1-2, and blocks x period, in order to determine whether some effects are repeated at 6-year intervals. The treatments are fixed, whereas B/y and E in principle are random variables.

The analyses of variance were mainly performed within the same crop and same crop sequence number, since comparisons between sequence numbers and between crops are of less interest. Furthermore, fertilizer treatment d had to be left out in calculating fertilizer x rotation variances because of lack of orthogonality.

The variability in yields of different crops is reported in Tables 1 and 2. The relative variability in Table 1 indicates that mean squares for period x fertilizer treatments and period x fertilizer x rotations are less than those for block x fertilizer or block x fertilizer x rotation. In Tables 3-7, therefore, lsd values (0.05) are given for block x fertilizer x rotation, which represents a more conservative test than lsd values based on block x per x fertilizer x rotation mean squares. For spring wheat, for instance, the lsd 0.05 would be reduced to $100/\sqrt{2} \times \sqrt{1.55} = 57\%$ in the last case.

The mean squares for error term (E_{ijkl}) from more than 2000 differences between the two replicates in this experiment are presented in Table 2. It should be noted that the mean square increases with increasing yield in dry matter, whereas the coefficient of variation (CV) behaves in the opposite way. The mean squares in lines 2 and 3 of the table are the Bl/y x treatments pooled values based on the averages of two replicates and therefore multiplied by two.

Table 1. Relative mean squares for blocks/years/periods x treatments within crops in rotation experiment, 1981-92

	Spring wheat	Barley	Oats	Grassland	Row crops
No. of yield figures	576	480	384	480	192
Block x fertilizer	131	120	106	150	89
Period "	203	78	77	132	73
Block x per x fertilizer	100	100	100	100	100
No. of yield figures	432	360	216	384	
Block x fertilizer x rotations	155	133	163	129	
Per. " "	76	78	88	126	
Block x per x fertilizer x rotations	100	100	100	100	

Table 2. Dry matter yield variations of different crops 1981-92

	Spring wheat	Barley	Oats	Grass	Row crops
Mean yield, tons/hectare	3.26	4.11	4.13	10.7	7.0
1. Mean squares (rep 1-rep 2) in tons/hectare^2 x 100	9.7	13.9	13.1	63.5	54.1
CV%	9.6	9.1	8.8	7.4	10.5
2. Mean squares B/y x f in tons/hectare^2 x 200	18.0	35.1	36.5	90.4	80.4
3. Mean squares B/y x f x r in tons/hectare^2 x 200	9.1	14.1	12.6	67.6	

The mean squares for B/y x fertilizer treatments are much greater than the between replicate variations, especially for barley and oats, whereas the B/y x fertilizer x rotations mean squares (line 3) are about the same as those in line 1. The B/y x fert. x rot. mean squares apply only for blocks with rotations of the same crops, and mostly for treatments a, b and c only. As reported, the experimental plan is a split block design, which affords the highest precision for the rotation x fertilizer determination. Since the expected mean square in line 3 in Table 2 is expected mean squares in line 1 + variation in the above interaction, we have to look for some additional explanations. The fertilizer x rotation effects are determined within small compact blocks, whereas the two real replicates were placed at a considerable distance apart, one in each half of the experimental field.

Nevertheless, the results demonstrate a relatively larger variation in B/y x fertilizer for barley and oats than for the wheat crop. This can be explained by the fact that the highest N-application rate was superfluous and in some years resulted in lodging and reduced yields of barley and oats. Some effect of the soil productivity on individual plots, repeated at 6-year intervals, might also be more important for grain crops than for hay crops. The hay yields comprise the totals for two harvests each year and, as might be expected, are less influenced by water and nutrient supplies in critical periods in the growth period.

RESULTS

Grain yields

Effects of rotations and fertilizer treatments including also FYM and straw upon the grain crops are presented in Tables 3, 4 and 5. The responses to ley in the rotations were highly positive for the first and second years after 4 years of grassland, and, for the first, second and third year after 2 years of grassland with clover, whereas such positive responses disappeared in the fourth year of arable crops after the 2 years ley.

Table 3. Means of dry matter grain yields of spring wheat in tons per hectare, 1981-92

Fertilizer treatment	a	b	c	d	aN	bN	cN	dN
Kg N per hectare	40	80	(80)	(80)	120	160	(160)	(160)
" P " "	25	35	(35)	(35)	25	35	(35)	(35)
" K " "	80	100	(100)	(100)	80	100	(100)	(100)
Crop sequence no. 5:								
I Spring wheat after oats	2.46	3.03	3.12	3.17	3.26	3.40	3.50	3.47
II " " " beet	2.51	3.06	3.31	3.18	2.94	3.31	3.34	3.35
III " " " ley 2	3.05	3.42	3.62	3.62	3.47	3.79	3.87	3.66
Responses 1st year after 2 years' ley III-I:	0.59	0.39	0.51		0.21	0.39	0.37	
Lsd, 0.05, for rotation x fertilizer combinations 0.29 tons per hectare								
Crop sequence no. 2:								
I Spring wheat after barley	2.49	3.18	3.08	3.12	3.01	3.37	3.31	3.34
III " " " ley 2	2.42	3.19	3.14	3.02	3.03	3.33	3.35	3.41
IV " " " ley 4	2.95	3.48	3.45	3.44	3.41	3.73	3.64	3.84
Responses 2 years after 4 years' ley IV-I:	0.46	0.30	0.31		0.40	0.36	0.33	
Lsd, 0.05, for rotation x fertilizer combinations 0.26 tons per hectare								

(1) Treatment d not comparable for I-II versus III-IV and values not included in variance tests

(2) Sequence no. 2 represents the first year after FYM in c I-IV and d III and IV. N and K in fertilizers therefore reduced by 20 kg per hectare. No reduction in N and K in crop sequence no. 5. Fertilizer P in FYM treatments reduced in all years (according to FYM analyses)

(3) In d I and d II K-fertilizer reduced by 20 kg per hectare in years after ploughing in cereal straw

(4) Lsd, 0.05, calculated from blocks x fertilizer x rotation mean squares. If the two 6-year periods are considered as independent replications lsd values (for block x period x fertilizer x rotation mean squares) would be greatly reduced (see Table 2)

Table 4. Means of dry matter grain yield of barley in tons per hectare, 1981-92

Fertilizer treatments	a	b	c	d	aN	bN	cN	dN
Kg N per hectare	40	80	(80)0	(80)0	120	160	(160)80	(160)80
P	25	35	(35)	(35)	25	35	(35)	(35)
K	80	100	(100)0	(100)0	80	100	(100)0	(100)0
Crop sequence no. 1: 60 tons FYM in c, (I-IV) and d (III-IV)								
I Barley after oats	3.09	3.92	4.13	3.93	4.18	4.30	4.37	4.41
III " " ley 2	3.44	4.29	4.35	4.21	4.27	4.47	4.47	4.33
IV " " ley 4	3.58	4.40	4.46	4.53	4.67	4.64	4.61	4.48
Responses third year after 2 years' ley, III-I:	0.35	0.37	0.22		0.09	0.17	0.10	
Responses 1st year after 4 years' ley, IV-I:	0.49	0.48	0.33		0.49	0.34	0.24	
Lsd, 0.05, for rotation x fertilizer combinations 0.34 tons per hectare								
Crop sequence no. 3:								
I Barley after spring wheat	2.80	3.70	3.66	3.76	3.81	4.10	4.14	4.26
II " " swedes and potatoes	3.23	4.05	3.99	4.11	4.10	4.15	4.42	4.27
Responses for 2 years of row crops. II-I:	0.43	0.35	0.33	0.35	0.29	0.05	0.28	0.01
II sequence 3 ÷ I sequence 1	0.14	0.13	0.14	0.18	-0.08	-0.15	0.05	-0.14
Lsd, 0.05, for rotation x fertilizer combinations 0.31 tons per hectare								

In the year of FYM application, sequence no. 1, N in fertilizer reduced by 80 kg and K by 100 kg per hectare (see also notes to Table 3)

Table 5. Means of dry matter grain yields of oats in tons per hectare, 1981-92

Fertilizer treatments	a	b	c	d	aN	bN	cN	dN
Kg N per hectare	40	80	80	80	120	160	160	160
" P " "	25	35	35	35	25	35	35	35
" K " "	80	100	100	100	80	100	100	100
Crop sequence no. 6:								
I Oats after spring wheat	3.20	4.00	4.05	4.06	3.94	4.29	4.28	4,22
II " " " " and beet	3.24	4.05	4.10	4.16	4.08	4.23	4.38	4.31
III " " ley 2	3.72	4.45	4.50	4.45	4.51	4.43	4.43	4.45
Responses 2nd year after 2 years' ley III-I:	0.52	0.45	0.45		0.57	0.14	0.15	
Lsd, 0.05, for rotation x fertilizer combinations 0.33 tons per hectare								
Crop sequence no. 4:								
I Oats after barley	2.94	4.04	4.04	4.22	4.10	4.11	4.42	4.15

The effects of increased fertilizer rates were mainly those of nitrogen, since P and K applications were liberal. Furthermore, the 80 kg N applied as a top dressing after sprouting apparently gave somewhat different results from those after the all-spring applications. On average, application of 40 + 80 kg N (aN) did not result in higher yields than application of 80 kg (b) before sowing, whereas 80 + 80 kg N (bN) usually did increase yields in the grain rotations. In many of the years periods of drought in early summer could have been responsible for the somewhat reduced efficiency of top-dressed calcium nitrate.

Some comparisons can also be made between sequence numbers. In a 6-year run all the representative crops have been grown on the same site, but in different years. Of particular interest are comparisons of spring wheat following after barley or after oats, and, likewise for barley after wheat or oats. In sequence no. 3 barley had a much better yield after 2 years of row crops, potatoes followed by swedes, than after spring wheat. However, the yields of barley grain crops were not much higher in the last rotation than those after oats in crop sequence no. 1 (Table 4) and the low yields of barley in sequence no. 3 could have been due to a previous effect of spring wheat. Barley and spring wheat are both susceptible to "take all" disease; however, no detrimental effects were revealed in spring wheat after barley, as compared with oats (Table 3).

The variation in total grain yields between years was large, although the responses to rotations and fertilizer treatment seemed to vary somewhat less. Yield figures and responses in the individual years will not be reported here. In years with high yield, lodging of barley, and also sometimes of oats, might result in irregular responses.

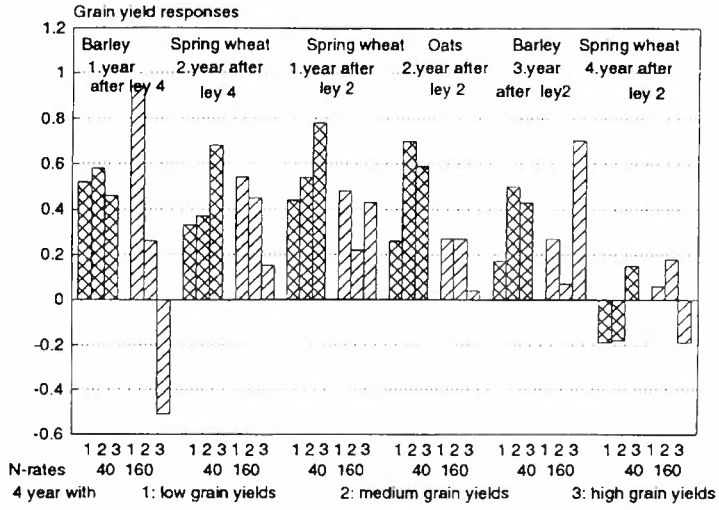

Fig. 1. Rotational effects of ley upon grain yields (tons/hectare) at low and high N-application rates (kg/hectare) and three different grain yield levels

In Fig. 1 grain yield responses for ley are shown in rotations of 40 and 160 kg N per hectare at low, medium and high grain yields respectively. Low grain yield represents 4 years with barley and oat yields of less than 3.5 tons per hectare and spring wheat yields of less than 2.6 tons. High grain yield, on the other hand, represents 4 years with barley and oat yields above 5 tons and spring wheat yields of 4 tons per hectare. The highest N rate at 160 kg per hectare has been overoptimal in the high-yield years for barley in the first year after a 4-year ley, and, also for oats in the second year after 2 years' ley. Spring wheat was less liable to lodging and reacted somewhat differently from barley and oats. At 40 kg N per hectare the tendency was towards a reduction in yield response in kilograms of grain for ley in rotation in low-yield compared with medium- and high-yield years.

Hay yields

The hay yields and the effects of fertilizers in the two ley rotations are shown in Table 6.

Table 6. Means of dry matter hay yields in tons per hectare, 1981-92

1st year ley:						Additional N in the previous year		
	a	b	c	d	a	b	c	d
Kg N per hectare	40	80	60	100	40	80	60	100
" " " "	+40	+60	+60	+80	+40	+60	+60	+80
" P " "	25	35	25	35	25	35	25	35
" K " "	120	160	140	180	120	160	140	180
Rotation III	9.7	10.3	10.3	10.8	10.0	10.8	10.5	11.2
" IV	9.6	10.4	10.4	11.0	9.6	10.7	10.7	11.1
Lsd, 0.05, for rotation x fertilizer combinations 0.67 tons per hectare								
2. year ley:	a	b	c	d	a	b	c	d
Kg N per hectare	40	100	80	140	40	100	80	140
" " " "	+40	+60	+60	+80	40	60	60	80
" P " "	25	35	25	35	25	35	25	35
" K	120	160	140	180	120	160	140	180
Rotation III	10.4	11.5	11.7	12.0	10.4	11.5	11.4	11.6
IV	10.5	11.8	11.6	12.5	10.3	11.8	11.5	12.2
Lsd, 0.05, for rotation x fertilizer combinations 0.74 per hectare								
3rd and 4th years' ley:	a	b	c	d				
Kg N per hectare	40	100	100	160				
" " " "	+40	+60	+60	+80				
" P " "	25	35	25	35				
" K " "	120	160	140	180				
3rd year ley IV	8.9	10.9	10.7	11.5	Lsd, 0.05,	0.56 tons per hectare		
4th " " IV	8.0	10.5	10.4	10.9	Lsd, 0.05,	0.82 tons per hectare		

In the year of establishing the ley crops an additional treatment with N was applied to half of each of the subplots. This had a great impact upon the amount of clover in the first ley year, as demonstrated in Fig. 2. However, despite the considerable reduction in clover content, the hay yields were not reduced. As can be calculated, the average first year yield indicated in the right half of Table 6 was 0.26 tons per hectare higher than in the left half of the table. The results appeared to be the same in the first and second cuts, but these values are not reported. No after-effects of additional N on clover percentage or yield were evident in the second ley year. This result can perhaps be explained by the fact that the detrimental effect on clover growth caused by the additional N to the cereal crop in the year of establishment was more than counteracted by the increased supply of N to the young timothy plants.

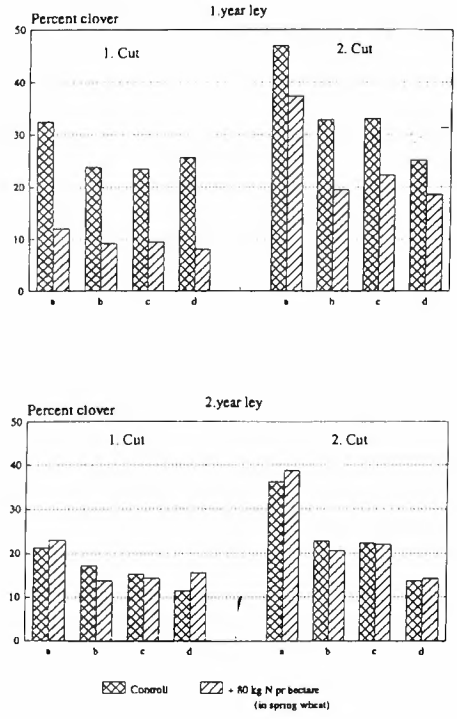

Fig. 2. Clover percentages of dry matter hay yields as affected by additional N (80 kg/hectare) in the establishment year. Mean values 1984-90

In treatments IIIc and d and IVc and d, FYM application were carried out two years ahead of the ley periods. Some reductions were therefore made in the fertilizer rates of treatment c, as can be seen from Table 6. In the 3rd and 4th ley years no corrections for N were made for FYM treatments.

The increases in grass dry matter yields from low to medium NPK rates (b-a) were about twice as high as the yield increases for the highest dose of NPK (d-c). No gain in cereal crop yield of the highest rate of NPK for ley has been proven (Tables 3-5).

In the third and fourth years of ley in rotation IV, relatively small amounts of clover survived and the values are therefore not given.

Row crops

The yields of swedes, beets and potatoes are recorded in Table 7. For potatoes and beets, all fertilizers were applied in spring before planting, whereas half of each swede plot received top dressing with 80 kg N per hectare. This additional N was reflected in swede top yields but there was little evidence of gains in root yields. In the potato year, 60 tons FYM was applied to treatment c. The fertilizer rates were corrected in c as reported in Table 7.

Table 7. Means of row crops' dry matter yield in tons per hectare, rotation II, 1981-92

Fertilizer treatment	a	b	c	d	aN	bN	cN	dN
Kg N per hectare	40	120	100	120	40 +80	120 +80	100 +80	120 +80
Kg P " "	25	35	25	35	25	35	25	35
Kg K " "	120	160	140	160	120	160	140	160
Swedes, root	5.9	7.1	7.5	7.3	7.1	7.2	7.7	7.3
" top	1.3	2.0	2.0	2.0	2.0	2.4	2.5	2.5

Lsd, 0.05, Swedes root 0.67 Swedes top 0.26 (tons per hectare)

	Beets				Potatoes			
	a	b	c	d	a	b	c	d
Kg N per hectare	80	160	140	160	80	160	80	160
" P " "	25	35	25	35	25	35	25	35
" K " "	120	160	140	140	120	160	60	140
FYM tons/hectare	-	-	-	-	-	-	60	-
Beet root	6.3	7.2	7.6	7.3				
" top	2.8	3.8	3.7	3.8				
Potato tubers					5.7	6.1	6.6	6.3

Lsd, 0.05: Beet root 0.55 Beet top 0.25 Potatoes 0.35 (tons per hectare)

Effects of farm manure (FYM) treatment

The effects of FYM, given once at a rate of 60 tons per hectare in the 6-year rotation, are reported in Table 8.

It should again be noted that the fertilizer rates with FYM were corrected in order to give exactly the same total amounts of P and K in 6 years for treatments c and b. The N application in calcium nitrate was also reduced, by 80 kg N in year 0 and 20 kg N in years 1, 2 and 3 after FYM, as compared with treatment b. The average amount of NH_4-N added in FYM per 6-year period (1981-92) was 108 kg and that of total-N 234 kg per hectare.

Table 8. Yield responses to farm manure (FYM) in tons of dry matter per hectare 1981-92. (c - b + cN - bN)/2

	Year after FYM application					
	0	1	2	3	4	5
I	Ba	Sp.wh	Ba	Oat	Sp.wh	Oat
	0.14	-0.08	0.00	0.15	0.09	0.02
II	Pot	Sw	Ba	Beet	Sp.wh	Oat
	0.46	0.42	0.10	0.31	0.14	0.10
III	Ba	Sp.wh	Ley 1	Ley 2	Sp.wh	Oat
	0.03	-0.02	-0.13	0.06	0.14	0.02
IV	Ba	Sp.wh	Ley 1	Ley 2	Ley 3	Ley 4
	0.02	-0.06	-0.03	-0.26	-0.18	-0.11

Ba = barley Sp. wh = spring wheat Sw = swedes Pot = potato

The results indicate that the after-effects of N from 60 tons FYM in the second to the fourth years were less than equivalent to 20 kg N per hectare. In the fifth and sixth years, where the same amount of N in fertilizers was applied to treatments c and b, small positive responses occurred for grain, but not for ley crops.

As shown in Table 8 the best yield effect of FYM is found for the row crops.

Effect of ploughed in straw

The straw yields from all grain crops, treatment d in rotations I and II, have been ploughed in in late autumn every year since 1953.

The straw yields which are not reported here have normally been amounted to 3-4 tons per hectare.

The effect of straw can be seen from Tables 3, 4, 5 and 7. The yield differences between treatments d and b were mostly positive, but small and not significant in any of the comparisons within the same crop sequence numbers. However, the overall effect of straw can be assessed from 216 comparisons of cereal crops in 1981-92. The average response over 12 years was +74 kg grain per hectare, which is significant according to a Student's t-test (Snedecor 1956).

In earlier periods it was found that the response to ploughed-in straw was more positive in oats than in barley crops (Uhlen 1981). In the last 12 years the average responses were 103, 72 and 43 kg per hectare in barley, oats and spring wheat, respectively.

The above values were averages for rotations I and II. As seen from the experimental plan, straw was ploughed-in only in 3 out of 6 years in rotation II. Tops of beet and swedes were removed. No clear differences in straw response (d-b) between rotations I and II were found. The responses to ploughed-in straw on the subsequent crop on potatoes and beet were +190 and +170 kg per hectare and on swedes in the second year after straw +140 kg dry matter per hectare.

Long-term rotational effects

The experimental plan for rotations and, in particular, the fertilizer rates has undergone some changes in the period 1954 to 1992. In the ley rotations III and IV a break was introduced in the 1970s. In order to measure residual effects of ley a period of 4 years' grain crops was taken also in rotation III and IV. The results in grain responses in the firth to the eighth year after ley are reported in Table 9.

Table 9. Grain yield responses for ley in tons dry matter per hectare. Rotation experiment, 1963-80

		Without FYM				FYM included	
		N1	N2	N3	N4	N2	N4
Kg N per hectare		31	52	73	94	(52)	(94)
1963-68:							
1st year after ley 2	Barley	1.09	0.85	0.68	0.43	0.69	0.39
2nd " " "	Oats	0.54	0.58	0.44	0.26	0.21	0.05
4th " " "	Barley	0.12	0.07			0.13	
1969-80:							
1th year after ley 2	Barley	0.88	0.72	0.58	0.51	0.60	0.19
2nd " " "	Oats	0.55	0.54	0.55	0.30	0.35	0.10
3rd " " "	Oats	0.27	0.25	0.18	0.36	0.50	0.32
4th " " "	Barley	0.09	0.13	0.05	0.15	0.13	0.08
5th-8th " " "	Barley and oats	0.08	0.14	0.14	0.19	0.09	0.12
1969-80:							
1st year after ley 4	Oats	0.76	0.65	0.52	0.69	0.72	0.57
2nd " " "	Barley	0.68	0.56	0.50	0.35	0.84	0.40
3rd " " "	Barley	0.65	0.22	0.43	0.31	0.31	0.40
4th " " "	Oats	0.60	0.43	0.43	-0.03	0.20	0.01
5th-6th " " "	Barley	0.26	0.28	0.16	0.25	0.29	0.39

The values can be compared with the corresponding yield responses for ley in Tables 3-5.

The interpretation of the results is complicated by the fact that N rates were much higher in 1981-92 than in earlier periods. Also, spring wheat was not grown in the period 1963-80. The general trends in yields, however, were very much the same in the earlier periods as those reported for the 1981-92 period. The after-effects of ley, especially those after 2 years' ley, diminished in the years after the ley periods, and also with increased nitrogen supply. Judging from all available grain response data, 2 or 4 years' ley in the rotations could not be replaced by FYM applied in normal quantities. At comparable N levels there seemed to be no clear interactions between FYM and ley effects upon grain yields.

DISCUSSION AND CONCLUSION

In this long-term experiment, rotations including 2 or 4 years' ley gave increased cereal yield compared to all grain or grain row crops rotation. A fall off in the positive after-effects of a 2-year ley period with clover was found with increasing N-fertilizer rates and with time distance from the ley period (Table 9). In the fourth year after 2 years' ley, the spring wheat yield was no higher than that after barley in the all-grain rotation in the period 1981-92. In an earlier period, 1963-80, only small responses were found in barley in the fourth year after a 2-year ley. Increased nitrogen supply from build-up reserves in the soil under ley may explain the above results.

The after-effects of a 4-year ley in the two subsequent grain years were much the same as those after the 2-year ley. Introducing four extra grain years in the 1970s in rotations III and IV revealed that the after-effects of a 4-year ley were more long-lasting and also somewhat less influenced by N-fertilizer rates than those of a 2-year ley period. In this connection it should be mentioned that Skøien (1993) found very high soil aggregate stability in samples from the 4-year ley rotation plots, and, furthermore, that the experimental field was limed twice in the 1970s increasing the pH level from 5.5 to above 6. This might have contributed to a higher breakdown rate of the organic reserves from the ley periods in the additional arable period in the 1970s.

The somewhat lower grain yield responses to ley in the period 1981-92 than in earlier periods can also be attributable to the N-application rates being higher in the last period. In some years with high grain yield, lodging gave a negative response for ley at surplus N application (Fig. 1).

For ten trials in farmers' fields in southeastern Norway, larger positive responses in grain yield were measured the first year after 2 years and 1 year of clover-grass than in the first year after 3 years' ley. The 3-year ley treatment gave a somewhat higher yield in the second year than the 2-year and 1-year ley treatments (Uhlen 1974). Similar results were found in a rotation experiment on heavy clay soil at Øsaker, southern Norway (Stabbetorp 1972).

Adding of 80 kg N per hectare after sprouting in spring grain in the year of establishment of ley crops reduced the clover content drastically in the first and second cuts in the first ley year. The hay yields in the first ley year were not reduced, however. It should be added that the additional N fertilizer did not cause lodging in spring wheat.

Rotation II with 3-year row crops and 3-year cereals is the most humus-consuming system in these experiments. In an earlier period, from 1954 to 1970, rotation II had five years of grain and only one year of row crops. Barley following row crops, potatoes, gave higher yields than barley in all grain rotations in 1955-70 (Uhlen 1981).

In the period 1981-92 the previous effect of beet upon spring wheat was small, whereas barley yielded more after two years of row crops, potatoes and swedes, than after spring wheat. This might, however, be caused by a negative after-effect of spring wheat.

FYM is associated with ley rotations. However, for the sake of comparison, FYM treatments were also included in the all-arable rotations in these experiments. In 1954-92 60 tons FYM per hectare was applied every six years to the same plots, i.e. treatment c and for ley rotations also to treatment d. Prior to 1980 the FYM was of a dry type (20% dry matter) and with less NH_4-N and higher total-N and P per ton. The reduction in

fertilizer N in the c treatment in relation to treatment b was 90 kg N per period, or per 60 tons FYM before 1980, against 140 kg after 1980. For three 6-year periods (1963-68, 1969-74 and 1975-80) yield responses for treatment c over b were found to be +0.09, +0.09 and +0.23 tons grain per hectare (Uhlen 1981). This perhaps indicates an accumulative residual effect of FYM, over time, which has not been confirmed in the period 1981-92 (Table 8). However, in this period it was found that the FYM treatment produced the highest response in row crops. The explanation may be that these crops utilize the nitrogen liberated from the organic fraction of the manure more efficiently than the grain crops. The mineralization of nitrogen from former applied FYM might, on the other hand, be slowed down in grassland compared to arable land. Also the after-effects of yearly ploughed-in straw (1954-92) tended to be greater in row crops than in grain crops. In addition to a small, but significant, grain yield increase (74 kg per hectare and year), K-fertilizer application could be reduced when the straw was brought back to the soil.

The gain from ploughed-in straw, like the positive residual effect of FYM, can largely be explained by the somewhat higher organic matter content in the soil, as reported elsewhere (Uhlen 1991). Some additional nitrogen mineralization from the residues was to be expected.

The effect of short-term ley in a ley-grain rotation has been temporary in this experiment. These results lend no support to the concern about the sustainability of an all-arable, grain-growing system without FYM or other organic matter amendments. As reported earlier (Uhlen 1991), no further downward trend in the humus content of this soil was apparent after a period of 15-20 years with continuous grain. In six long-term rotation experiments in southern Sweden a long-term rotation effect as well as a previous crop effect of ley (one year out of four) upon grain yield and N supply from the soil were demonstrated (Persson & Mattsson 1993), and in a Danish 30-year experiment relatively large reductions in C and N in soil were found, especially in all-arable crop rotations. Since such effects are likely to be influenced by soil type as well as climatic factors, more long-term experiments of this type should be carried out.

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Control of flowering in *Phalaris arundinacea*

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Seedlings of reed canarygrass (*Phalaris arundinacea* L.) have a dual photoperiodic induction requirement for flowering. Exposure to short days (SD) for 12 to 18 weeks at temperatures ranging from 6 to 15°C is required for primary induction, while a transition to long days (LD) is required for initiation of floral primordia, heading and inflorescence development (secondary induction). Primary induction is greatly enhanced by high photon flux density. The critical photoperiod for secondary induction was found to vary from about 13 h in the American cv. Vantage to about 15 h in Norwegian cvs. and breeding lines. A minimum of 8 LD cycles was required for secondary induction whereas 16-20 cycles were required for the full response. Plants grown in LD conditions developed elongated culms, even without primary induction. Such elongated shoots cannot be induced to flower. Spraying with the gibberellin biosynthesis inhibitor CCC reduced growth and enhanced primary induction in both SD and LD conditions. It is suggested that the effects of SD are mediated by lowering of the level of active gibberellins.

Key words: Flowering, gibberellin, growth, induction, *Phalaris arundinacea*, photoperiod, temperature.

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Reed canarygrass (*Phalaris arundinacea* L.) is a promising forage grass for the Nordic countries as well as for the Midwest of the USA and Canada. In Sweden it is also being evaluated as a short-rotation fibre and fuel crop species. Native to most of Norway, it comprises a broad range of local populations which have been tested for various physiological traits and agronomic performance (e.g. Landgraff & Junttila 1979; Berg 1980, 1982) and which, together with foreign materials, have been utilized in a national forage breeding programme (Simonsen 1983). However, the feed value of *P. arundinacea* is often limited by the presence of indole alkaloids of various types and concentrations (Marten et al. 1976), and breeding programmes for modified alkaloid composition have been necessary (Barker & Hovin 1974).

Such breeding programmes have often been restrained by the lack of reliable protocols for floral induction control, especially early in the ontogeny of the plant. Poor panicle formation and low seed yield in the field (e.g. Østrem 1988) have also delayed the adoption of the new crop owing to lack of available seed, especially of newly released cultivars. For

these reasons it was judged important to determine the floral induction requirements of the species and, in particular, those of Norwegian populations and breeding lines which often have poor flowering and seed production performance (e.g. Berg 1982; Østrem 1988).

Most temperate perennial grasses have a dual induction requirement for flowering; a primary induction requirement which is met by decreasing daylength and temperature during autumn and winter, and a secondary induction requirement met by the increasing daylength and temperature during spring and early summer. A few species, such as *Phleum pratense* and *Poa nemoralis*, require only long days (LD) and have no winter requirement for flowering (for a review see Heide 1994).

Allard & Evans (1941) classified *P. arundinacea* as a LD plant and estimated the critical daylength to 13.5 h. However, the plants had previously been subjected to winter conditions, so only the secondary induction requirements were exposed. A large primary induction requirement was indicated by the results of Hanson & Sprague (1953), and Bommer (1959) found that *P. arundinacea* was one of the latest species to initiate inflorescence primordia under field conditions (in late April). Heichel et al. (1980) found that seedlings of the American cvs. Vantage and Rise required 12 to 15 weeks' exposure to 8-h short days (SD) at 6°C for primary induction in growth chambers (175 μmol $m^{-2}s^{-1}$ PAR). About 75% of the plants then flowered after return to high (27/19°C day/night) temperature and 16-h photoperiod, whereas only 40-50% flowered after exposure to 16-h photoperiod/6°C. The presence of a non-sensitive juvenile stage was demonstrated, but 4-week-old seedlings with three fully emerged leaves were fully responsive (Heichel et al. 1980).

The objective of the present investigation was to determine the range of inductive temperature and daylength conditions for primary and secondary induction of flowering in *P. arundinacea*, with special emphasis on the response of Norwegian genotypes under varying light conditions. In order to explore the involvement of gibberellins in the primary induction process, treatment with the gibberellin biosynthesis inhibitor CCC was also included.

MATERIALS AND METHODS

Three Norwegian genotypes of *Phalaris arundinacea* L. were compared with the American cv. Vantage; viz. the recently released cv. Lara and the advanced breeding lines Sr 3001 and Sr 8401. Lara and Sr 3001 were bred and selected at Løken Experimental Station located in the continental area of South Norway (61°N, 550 m a.s.l.), and Sr 8401 at Vågønes Experimental Station located in the coastal area of North Norway (67°N, 10 m a.s.l.). Seeds of the Norwegian types were provided by the Norwegian forage breeding programme, whereas those of cv. Vantage were of commercial source.

The experiments were conducted in the Ås phytotron as described by Heide (1987). Plants were raised in 8-cm plastic pots at 21°C in 12-h photoperiod. Primary induction treatments were started after 5 weeks when the plants had developed three to four tillers and at least four fully emerged leaves on the main tiller. The 6°C treatments (and in one case 9°C for light comparison) were established in growth rooms illuminated with a mixture of Philips TL 32 fluorescent tubes and incandescent bulbs (120 μmol m^{-2} s^{-1}, PAR).

Otherwise, all experiments were performed in natural light in phytotron compartments which during August to April were supplemented with 112 μmol m^{-2} s^{-1} PAR from high pressure mercury lamps (Philips HPI-T 400W). Temperatures were controlled to $\pm$ 0.5°C and a water vapour pressure deficit of 530 Pa was maintained at all temperatures above 6°C.

All plants received the basic illumination as described for 8 h per day. Daylength treatments were established by moving the plants into adjacent growth rooms with either darkness (8 h photoperiod) or low intensity light (2 $\pm$ 0.05 μmol m^{-2} s^{-1}) from 75 W incandescent lamps for the desired daylength extensions.

CCC [(2-chloroethyl)-trimethylammonium chloride], obtained as a technical preparation (Cycocel with 40% CCC w/v from Cyanamid International), was diluted with distilled water to the concentrations indicated and then sprayed onto the plants on the day before start of the primary induction treatments. The entire foliage was wetted to drip-off (about 0.3 ml per plant). Control plants were sprayed with distilled water.

After completion of the primary induction treatments the plants were returned to higher temperatures (usually 18°C) and the desired photoperiods for secondary induction. At this stage the plants were transplanted into 12-cm plastic pots. Percentage flowering plants and number of panicles per plant were used as the main criteria of flowering, while culm height at anthesis and rate of flower development (days to heading) were used as additional criteria. Statistical analysis (ANOVA) of data was carried out according to standard methods (Snedecor & Cochran 1967). Ten uniform plants were used in each treatment.

RESULTS

Primary induction

Preliminary experiments revealed that plants exposed to 6°C and SD conditions for up to 12 weeks in artificial light seldom flowered when returned to warm, LD conditions. Treatments were therefore extended up to 21 weeks at 6°C in SD and LD (8 and 24 h photoperiods).

Under SD conditions the plants remained dwarfish with abundant tillering, short leaves and no stem elongation, whereas in LD conditions they grew with extended culms to a height of 50-80 cm after 21 weeks (Fig. 1). An exception was Sr 8401 of high-latitude origin, which remained in the same dwarfish condition in SD an in LD at this temperature. After 12 weeks' exposure to SD only a few plants flowered, while the percentage of flowering plants increased with increasing exposure time up to 18 weeks in three of the cultivars, and to 21 weeks in Sr 8401, which had the lowest flowering rate (Fig. 2). However, no more than 80% of the plants flowered in any treatment; in Sr 8401 the maximum was only 40%. The number of panicles was also low, and with a pattern of response similar to that for the percentage of flowering plants (Fig. 2). No flowering took place in plants exposed to LD, regardless of exposure time.

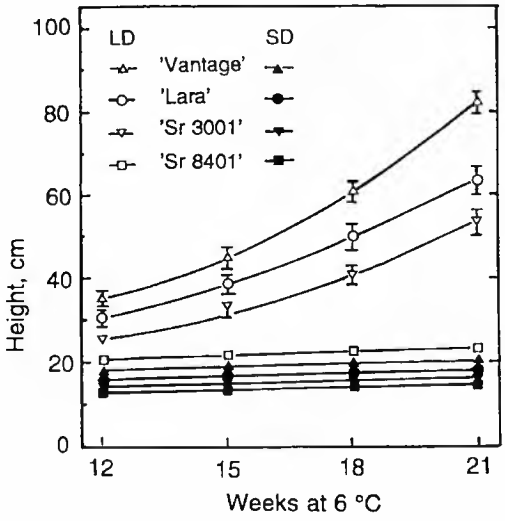

Fig. 1. Time courses of height growth in four cultivars of *P. arundinacea* during exposure to 6°C in short (SD) and long days (LD). Height to the tip of the uppermost leaf ± SE of 10 plants per treatment

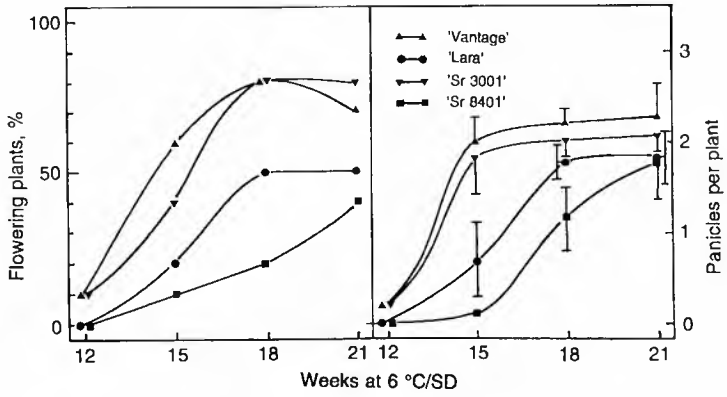

Fig. 2. Flowering response in four cultivars of *P. arundinacea* after exposure to SD at 6°C for 12 to 21 weeks in artificial light conditions followed by transfer to 18°C and 24-h LD. Plants exposed to 6°C and LD for the same periods did not flower. Means of 10 plants per treatment. Vertical bars represent 2 x the standard error of the means (± SE)

Since observations indicated stronger flowering response under daylight conditions, an experiment was set up with cv. Lara exposed to SD and LD at 9°C in natural summer daylight conditions (12-18 weeks' exposure). As shown in Fig. 3, 80% of the plants flowered after 12 weeks' exposure to SD, and after exposure for 14 weeks or longer all plants flowered. Also the number of panicles was higher than in the previous experiment, increasing to an optimum after 14 weeks' exposure, whereupon the number decreased again with longer exposure. After 16 or 18 weeks' exposure one or two plants produced a single panicle also in the LD treatment (Fig. 3).

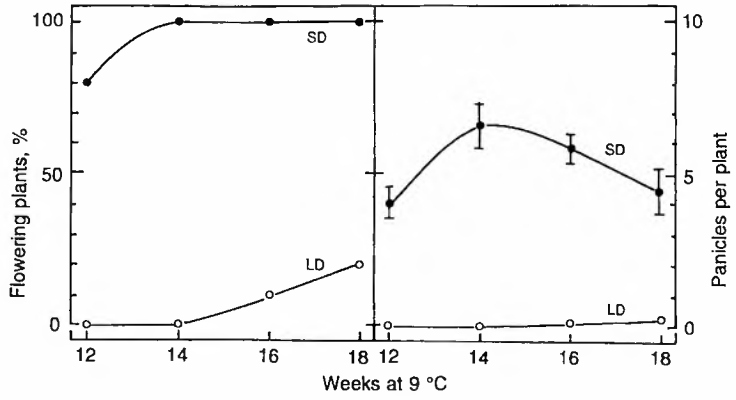

Fig. 3. Flowering response in cv. Lara after exposure to SD and LD at 9°C in natural summer daylight conditions for 12 to 18 weeks. Otherwise as for Fig. 2

For direct comparison of the light conditions, plants of three cultivars were exposed to 9°C/SD for 9, 12 and 15 weeks in summer daylight and artificial light conditions. Under summer daylight conditions a high proportion of plants of cvs. Vantage and Lara flowered even after only 9 weeks' exposure. After 12 or 15 weeks' exposure all or almost all plants of these cvs. flowered with an average of five to six panicles per plant (Fig. 4). Again, Sr 8401 was less responsive and required longer exposure to flower than the other cvs. In artificial light, however, hardly any flowering took place after 9 weeks' exposure, and even after 15 weeks, only 50-60% of the plants flowered with maximally two panicles per plant. On the other hand, there were no significant differences in flowering among the cultivars under these conditions (Fig. 4).

Abundant floral induction in SD under summer daylight conditions was also demonstrated in another experiment with three different temperatures (Table 1). With 18 weeks' exposure, as used here, constant temperatures of 9 and 12°C and a fluctuating day/night temperature of 15/9°C (8:16 h) produced abundant flowering. Again, Sr 8401 was least responsive with the lowest number of panicles and with only 70% flowering at 12°C, whereas cvs. Vantage and Lara had the highest number of panicles. Less flowering in Sr 8401 was associated with later heading and reduced culm height (Table 1).

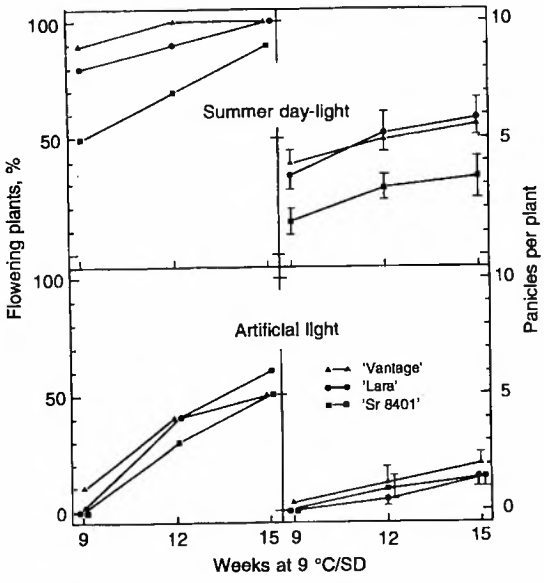

Fig. 4. Flowering response of three cultivars of *P. arundinacea* after exposure to SD at 9°C for 9 to 15 weeks in natural summer daylight and in artificial light (120 μmol m^{-2} s^{-1} PAR). Otherwise as for Fig. 2

Table 1. Effects of temperature on short day (SD) induction of flowering under summer daylight conditions in four genotypes of *P. arundinacea*. Values are means ±SE of 10 plants per treatment. Plants were exposed to 8-h SD at the respective temperatures for 18 weeks, whereupon they were returned to 24 h photoperiod at 18°C

Cultivar /line	Temp. °C	% flowering plants	Panicles per plant	Days to heading[1)]	Culm height, cm[2)]
Vantage	9	100	10.9±1.2	26.3±0.7	132±4
	12	100	8.1±0.9	30.4±1.5	127±4
	15/9(D/N)	100	10.1±0.7	33.0±1.0	123±5
Lara	9	100	10.2±1.3	27.8±1.5	124±5
	12	100	9.7±0.9	30.5±1.4	131±5
	15/9(D/N)	100	10.0±1.6	37.6±1.8	129±3
Sr 3001	9	100	8.6±1.0	30.1±1.0	117±4
	12	100	8.8±0.8	33.3±1.5	118±6
	15/9(D/N)	100	8.2±1.0	34.6±1.5	117±6
Sr 8401	9	100	6.4±0.9	37.6±2.1	104±6
	12	70	5.6±1.2	40.6±3.9	105±8
	15/9(D/N)	100	7.0±1.7	40.5±1.7	110±5

[1)] Days from transfer to 18°C and new photoperiod.
[2)] Height at anthesis

Two experiments examined the effects of the gibberellin biosynthesis inhibitor CCC on plant growth and primary induction of flowering under daylight conditions. Plant heights after 18 weeks under SD and LD conditions at 9°C in control and CCC-treated plants are presented in Fig. 5. While no stem elongation took place under SD conditions in any of the cultivars, Vantage and Lara elongated extensively in LD conditions with culm heights of 100-120 cm in control plants. In Sr 8401, on the other hand, plant heights were only slightly increased by LD, mainly due to some stimulation of leaf growth (Fig. 5). CCC significantly reduced plant heights in both LD and SD. An ANOVA analysis of the height data revealed highly significant main effects ($p < 0.01$) of cultivar, photoperiod and CCC, highly significant two-factor interactions of photoperiod x cultivar and photoperiod x CCC, as well as a significant ($p < 0.05$) three-factor interaction of photoperiod x cultivar x CCC.

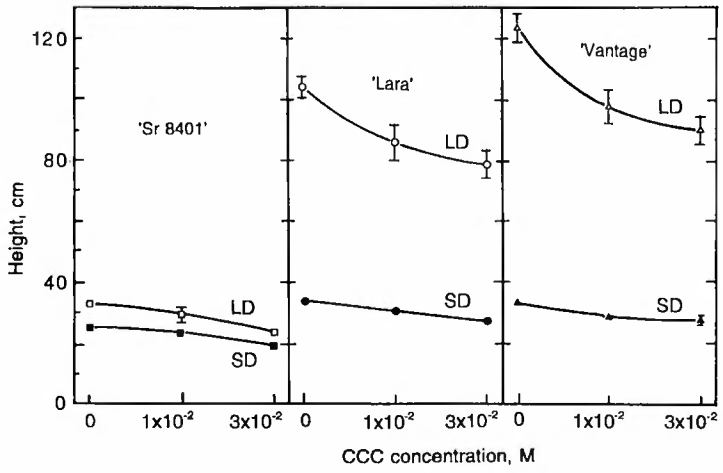

Fig. 5. Effects of CCC treatment on plant heights in three cultivars of *P. arundinacea* after exposure to SD and LD at 9°C for 18 weeks under natural summer daylight conditions. Means ± SE of 10 plants per treatment

In the SD-grown plants, flowering was not significantly affected by CCC (Fig. 6). In cvs. Vantage and Lara all plants flowered with an average of 4-5 panicles per plant in both control and CCC-treated plants. As usual, both frequency of flowering and number of panicles were lower in Sr 8401, but neither in this line there was any significant effect of CCC in SD. In LD, however, flowering in Sr 8401 was markedly stimulated by CCC, with an increase from 10% flowering in the control to 50% with 1 x 10^{-2}M CCC, and with a parallel increase in the number of panicles. However, there was no further increase in flowering with the highest CCC concentration. With the exception of one plant of cv. Lara, no induction of flowering took place in LD in the rapidly elongating plants of cvs. Vantage and Lara either in the presence or absence of CCC (Fig. 6). Apparently, only the short, non-elongating tillers are able to undergo primary induction of flowering.

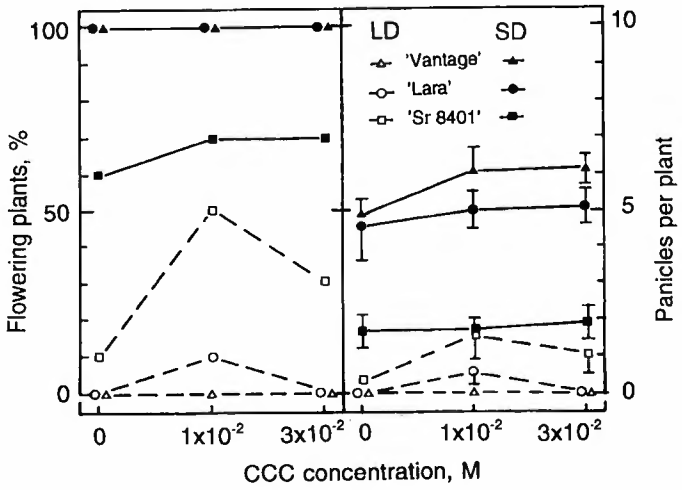

Fig. 6. Effects of CCC treatment on flowering response of three cultivars of *P. arundinacea* after exposure to SD and LD at 9°C for 18 weeks under natural summer daylight conditions. Otherwise as for Fig. 2

A statistical analysis of the panicle number data revealed highly significant main and interaction effects of cultivar and photoperiod ($p<0.01$), but no significant main effect of CCC due to significant interactions ($p<0.05$) of cultivar x CCC and cultivar x photoperiod x CCC.

The effect of CCC was also tested in cv. Lara under natural autumn daylength conditions during the period when primary induction takes place in the field. Control and CCC-treated plants were exposed to constant temperatures of 9, 12 and 15°C and fluctuating day/night temperatures of 15/9°C (8:16 h) for 18 weeks. The experiment was replicated in time three times with start of treatments on 1 Sept., 22 Sept., and 13 Oct., respectively.

Table 2. Effects of temperature and CCC on primary induction of flowering in cv. Lara under natural SD conditions. Plants were sprayed with CCC before exposure to the respective temperatures for 18 weeks. Values represent percentage of flowering plants and are based on three replications in time, started on 1 Sept., 22 Sept. and 13 Oct., respectively, each with ten plants in each treatment

Temp.	CCC concentration, M			
°C	0	1 x 10^{-2}	3 x 10^{-2}	Mean
9	96.7	100.0	100.0	98.9
12	96.7	100.0	100.0	98.9
15	80.0	86.7	86.7	84.4
15/9 (D/N)	90.0	100.0	100.0	96.7
Mean	90.8	96.7	96.7	

The percentage of flowering plants was high in all treatments with only a slight increase in CCC-treated plants (Table 2). Constant 15°C was less effective than the lower temperatures. The number of panicles per plant decreased with increasing temperature from 9 to 15°C (Table 3). This effect was highly significant ($p < 0.001$) in the ANOVA analysis. Fluctuating day/night temperatures were no more effective than corresponding constant ones. There was a significant positive flowering effect of CCC ($p < 0.05$), the effect being largest at 15°C where induction was weakest. This temperature x CCC interaction was not statistically significant, however.

Table 3. Effects of temperature and CCC on primary induction of flowering in cv. Lara under natural SD conditions. Plants were sprayed with CCC before exposure to the respective temperatures for 18 weeks. Values represent mean number of panicles per plant ±SE of three replications in time, started on 1 Sept., 22 Sept. and 13 Oct., respectively, each with 10 plants in each treatment

Temp.	CCC concentration, M			
°C	0	1×10^{-2}	3×10^{-2}	Mean
9	6.4±0.5	6.0±0.3	7.3±0.3	6.6±0.2
12	5.0±0.4	6.2±0.6	5.7±0.4	5.6±0.3
15	2.8±0.5	4.0±0.6	4.2±0.5	3.7±0.3
15/9 (D/N)	5.0±0.6	4.9±0.4	5.4±0.4	5.1±0.3
Mean	4.6±0.3	5.3±0.3	5.7±0.2	

The number of panicles increased only slightly in the successive replications, the effect being non-significant, indicating that the critical daylength had been reached by 1 September. However, in comparison with the results in Table 1, the lower light intensities during autumn and winter appear to be less favourable for floral induction than summer daylight conditions. Culm height and time of heading were not affected by the treatments (results not shown).

Secondary induction

The critical photoperiod for inflorescence initiation and development was examined at 18°C in three genotypes (Table 4). Plants were primary induced at 6°C/SD for 21 weeks in artificial light before exposure to the respective photoperiods for 35 days.

Culm heights after 35 d of treatment are presented in Fig. 7. The main height increase occurred over the daylength range between 13 and 15 h, indicating a critical daylength in this range. This was confirmed by the flowering response, with critical daylengths of about 15 h in the two Norwegian breeding lines and 13 h in cv. Vantage (Table 4). The highest number of panicles developed at 17 and 15 h, respectively with some decrease at longer photoperiods. Such an optimum at near-critical daylengths was also demonstrated in other dual induction grasses such as *Dactylis glomerata* (Heide 1987) and *Festuca pratensis* (Heide 1988), apparently attributable to favourable and very rapid development of 'leading' tillers in extended photoperiods. However, since primary induction had not been complete under artificial light conditions even with 21 weeks' exposure (cf. Fig. 4), inflorescence

numbers were always low. Days to heading decreased and culm height at anthesis increased with increasing photoperiod in all genotypes (Table 4). The low-flowering line Sr 8401 had both the slowest development and the shortest culms.

Table 4. Effects of photoperiod on heading and flowering (secondary induction) at 18 °C in three genotypes of *P. arundinacea*. Values are means ±SE of 10 plants per treatment. The plants had previously been exposed to 6 °C/8-h SD in artificial light (120 μmol m^{-2} s^{-1} PAR) for 21 weeks for primary induction

Cultivar /line	Photoperiod, h	% flowering plants	Panicles per plant	Days to heading[1)]	Culm height, cm[2)]
Vantage	8	0	0	>47	-
	13	60	1.4±0.5	41.3±2.2	68±8
	15	70	2.3±0.6	34.8±5.0	111±6
	17	60	2.1±0.4	28.6±1.2	108±9
	19	60	1.2±0.4	29.0±3.6	116±5
	24	60	1.2±0.4	28.6±3.8	122±8
Sr 3001	8	0	0	>47	-
	13	0	0	>47	-
	15	60	1.6±0.5	38.1±4.0	86±8
	17	70	2.0±0.4	37.0±5.8	90±5
	19	70	1.2±0.4	35.5±2.5	92±5
	24	60	1.2±0.4	26.7±0.6	117±5
Sr 8401	8	0	0	>47	-
	13	0	0	>47	-
	15	70	1.5±0.5	41.3±2.6	73±6
	17	60	1.8±0.7	38.3±5.4	96±9
	19	60	1.4±0.7	32.7±3.0	97±5
	24	50	1.2±0.5	31.7±2.6	113±7

[1)] Days from transfer to 18°C and new photoperiod
[2)] Height at anthesis

The critical number of 24-h LD cycles for inflorescence initiation and development was examined in another experiment at 15°C using the same primary induction treatment. Culm heights after 50 days (Fig. 8) showed a more or less linear increase with an increasing number of LD cycles. Marginal initiation and heading occurred with only 4 LD cycles, but plants developed very slowly with short culms and partially aborted inflorescences. Both percentage of flowering plants and number of panicles increased with increasing number of LD cycles; up to 20 LD in the Norwegian types, and up to 16 LD in cv. Vantage (Table 5). Again, Sr 8401 had the poorest flowering, accompanied by slower development and shorter culms (Fig. 8). Clearly, this high-latitude line had the greatest and cv. Vantage the smallest LD requirements (Table 5). As in the previous experiment, there was a general low flowering level because of suboptimal primary induction.

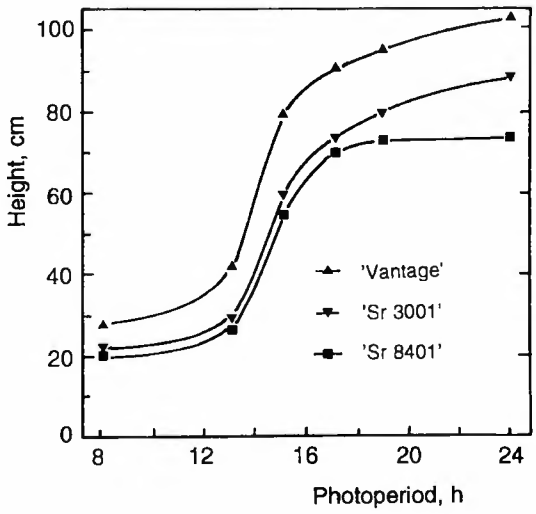

Fig. 7. The effect of photoperiod at 18°C on culm heights in three cultivars of *P. arundinacea* which were previously exposed to 9°C/SD for 21 weeks in artificial light conditions. Mean culm heights as measured to the ligule of the uppermost expanded leaf on the tallest shoot in each of 10 plants after 35 days of treatment

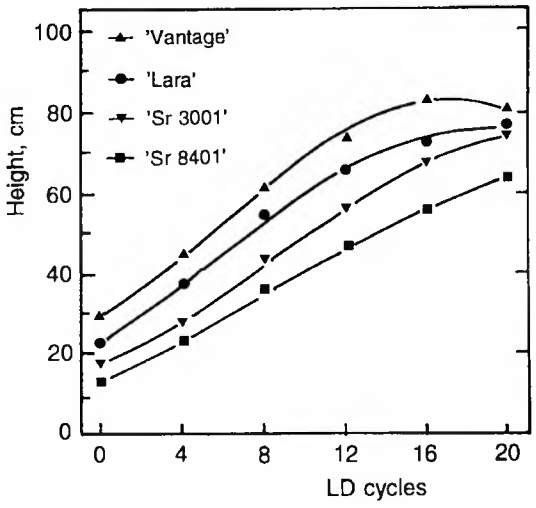

Fig. 8. Culm heights in four cultivars of *P. arundinacea* given a varying number of 24-h LD cycles at 15°C following exposure to 9°C/SD for 21 weeks in artificial light conditions. Following the LD cycles, plants were returned to 8-h SD while the temperature was continued at 15°C. Culm heights as indicated for Fig. 7 were recorded 50 days after the first LD was given

Table 5. Effects of varying number of 24-h long day (LD) cycles on heading and flowering (secondary induction) at 15°C in four genotypes of *P. arundinacea*. Values are means ± SE of 10 plants in each treatment. Primary induction as in Table 4

Cultivar /line	Number LD cycles	% flowering plants	Panicles per plant	Days to heading[1)]	Culm height, cm[2)]
Vantage	0	0	0	>70	-
	4	30	0.7±0.4	59.0±4.6	65±2
	8	40	1.1±0.5	46.3±2.8	80±4
	12	40	2.0±0.4	40.5±0.3	99±2
	16	80	2.2±0.4	39.4±0.8	102±4
	20	80	1.4±0.2	40.2±1.2	95±3
Lara	0	0	0	>70	-
	4	30	0.9±0.4	63.8±2.9	57±3
	8	50	1.6±0.4	53.0±5.1	72±7
	12	60	1.6±0.4	45.0±1.7	83±5
	16	50	1.3±0.3	39.0±1.2	97±6
	20	70	2.0±0.4	41.0±1.2	103±6
Sr 3001	0	0	0	>70	-
	4	30	0.8±0.4	60.0±2.1	53±3
	8	50	1.4±0.6	54.2±4.2	71±8
	12	60	1.3±0.5	46.7±2.0	72±2
	16	90	2.0±0.4	43.1±2.1	79±4
	20	80	2.3±0.6	39.4±1.6	90±3
Sr 8401	0	0	0	>70	-
	4	10	(0.1)	(66)	(65)
	8	30	0.4±0.2	64.7±3.8	68±4
	12	20	0.4±0.2	67.5±1.5	83±5
	16	40	0.6±0.3	46.0±1.0	79±3
	20	60	1.3±0.3	43.3±2.8	84±5

[1)] Days from first LD
[2)] Height at anthesis

In none of these experiments was there any heading or flowering under continuous SD conditions. Dissection and anatomical examination of the zero LD plants at harvest after 70 days, i.e. after 31 weeks of continuous SD treatment at inductive temperatures, revealed that apices were still in the vegetative state (results not shown). This demonstrates that inflorescence initiation in this species has an absolute requirement for a transition from SD to LD. The effect of primary induction, a prerequisite for the process, is thus not realized until such a shift in daylength takes place.

Genotypic variation in daylength requirements was also demonstrated in a third experiment. Plants were primary induced at 9°C/SD for 16 weeks during the winter and then transferred to natural daylengths at 18°C in the phytotron on 10 April.

Table 6. Flowering in four genotypes of *P. arundinacea* under natural daylength conditions at 18°C. Values are means ±SE of 12 plants in each treatment. Plants were exposed to 9°C/8-h SD in daylight conditions for 16 weeks for primary induction whereupon they were transferred to 18°C and natural daylengths on 10 April

Cultivar /line	% flowering plants	Panicles per plant	Total no. of tillers	Days to heading[1)]	Culm height, cm[2)]
Vantage	92	6.7±0.9	19.8±1.5	33.6±2.0	139± 7
Sr 3001	89	5.2±1.3	25.0±2.4	42.2±1.8	130± 8
Lara	75	4.4±1.0	26.9±2.6	40.0±2.6	123±10
Sr 8401	42	1.1±0.5	34.3±2.0	55.7±5.5	95± 8

[1)] Days after 10 April
[2)] Height at anthesis

The results in Table 6 confirm the variation in flowering tendency and primary induction requirements among the cultivars and breeding lines. They also confirm the stronger LD requirement for heading and flowering in the Norwegian genotypes as compared with cv. Vantage. By making a comparison with the data for days to heading in Table 4, it can be estimated that critical daylengths were reached by about 10 April in cv. Vantage, by about 20 April in Lara and Sr 3001, and by early May in Sr 8401. The civil daylength at Ås (59°40'N) on these dates varies from about 14 h on 10 April through 15 h on 20 April, to about 16 h by 1 May. These estimates give comparable but slightly longer critical daylengths than those derived from Table 4.

Table 7. Mean number of panicles and tillers per plant for the four genotypes of *P. arundinacea*. Values are means ± SE for six experiments with n = 18 for each genotype

Cultivar /line	Panicles per plant	Tillers per plant
Vantage	3.9±0.7	14.3±1.2
Lara	3.7±0.8	15.1±1.6
Sr 3001	3.5±0.6	15.8±1.4
Sr 8401	1.8±0.4	18.1±1.6

As also noticed in the preceding experiments, there was a negative relationship between flowering and tillering capacity among the cultivars (Table 6). The mean values for these parameters from a total of six experiments which included all four cvs. are summarized in Table 7. The correlation coefficient between panicle and tiller numbers for the cultivars is $r = -0.977$ ($n=4$), which is significant at $p < 0.001$.

DISCUSSION

The results clearly demonstrate the dual induction requirement for flowering in *Phalaris arundinacea,* which can be classified as a short-long-day plant. The strong primary induction requirement is fulfilled by exposure to SD at temperatures ranging from 6 to 15°C, with optimum at 9-12°C, for 12-18 weeks depending on genotype and temperature conditions (Figs. 2-4). While confirming the earlier results of Heichel et al. (1980) for the American cv. Vantage, the results also demonstrate an even larger primary induction requirement in Norwegian cvs. and breeding lines, especially the high-latitude Sr 8401 (Figs. 2, 4, 6, Tables 1, 5, 6). This deviates from the general trend of more laxed primary induction requirements in high-latitude grasses (e.g. Heide 1980, 1989, 1994). The marked negative correlation between tiller number and flowering among the cultivars demonstrated in Table 7 suggests that selection for high herbage production in the breeding programme has favoured tillering at the expense of flowering capacity. Clearly, too profuse tillering can produce a dense stand of weak tillers with low flowering capacity, a situation which is commonly observed in seed production stands of *P. arundinacea*. The finding that even moderate defoliation before onset of primary induction drastically reduces flowering (Heichel et al. 1980) underlines the importance of strong tillers with favourable carbohydrate status for good flowering in this species.

This is probably also the basis for the high photon flux density (light intensity) requirement for primary induction in this species. Not only was a photosynthetic photon flux density of 120 μmol m^{-2} s^{-1} insufficient for good primary induction in the present experiments (e.g. Fig. 4), but also 175 μmol m^{-2} s^{-1} as used by Heichel et al. (1980) was clearly underoptimal and never produced more than 80% flowering. In both cases a combination of cool-white fluorescent and incandescent lamps was used. Although a light quality effect thus cannot be excluded in the comparison with summer daylight conditions, the effects of defoliation and high shoot density (discussed above), indicate primarily a light intensity effect.

Most dual induction grasses form elongated culms in LD only if previously primary induced to flower by SD and/or low temperature (Heide 1994). Together with *Bromus inermis* (Heide 1984), *P. arundinacea* represents an exception to this and forms elongated culms in LD even in non-primary induced plants (Figs. 1 & 5). While being a key element in the high productivity of these grasses in LD conditions, this characteristic also confers special floral induction responses on these grasses. Indeed, such elongated tillers are unable to undergo primary induction and they will therefore remain vegetative (barren). As a consequence, hardly any primary induction takes place under LD and low temperature conditions in these species. These responses differ from those of *Phalaris aquatica* (syn. *P. tuberosa*), which is equally well induced by low temperature in SD and LD (Cooper & McWilliam 1966; McWilliam 1968) and has a much shorter exposure requirement (Ketallapper 1960).

The special growth responses of the high-latitude line Sr 8401 are interesting in this context. Unlike the other genotypes, Sr 8401 did not elongate under LD conditions at 6 and 9°C (Figs. 1 & 5), whereas elongation was comparable with that of the other genotypes at 15 and 18°C (Figs. 7-8). This modification of the LD response at low temperature seems important both for primary floral induction (Fig. 6) and for winter survival in the high-

latitude environment where freezing temperatures can occur before SD in the autumn. This line has been selected specially for winter survival at high latitudes and it seems that this is associated with the ability to stop elongation growth early in the autumn in response to reduced temperatures while still in LD.

Since both non-inductive LD conditions and gibberellin (GA) treatment greatly stimulate leaf (in *B. inermis* and *P. arundinacea* also stem) growth in many dual induction grasses (Hay & Heide 1983; Heide et al. 1985), the degree of primary induction is negatively correlated with elongation growth (e.g. Heide 1984, 1986, 1987) as also demonstrated in the present experiments. Also, in *Poa pratensis* and *Bromus inermis* weekly applications of GA_3 during primary induction were strongly inhibitory to flowering (Heide et al. 1987). It was therefore suggested that primary induction of flowering in dual induction grasses is mediated by a reduction in the level of active gibberellins (Heide et al. 1987). In other words, that the effect of SD and/or low temperature is to remove the inhibitory effect of LD and the resulting high GA level (Heide 1994). The hypothesis is compatible with the daylength control of important steps in the GA interconversion pathway reported in several other species (Gilmour et al. 1986; Graebe 1987; Junttila & Jensen 1988).

In agreement with this hypothesis, the GA biosynthesis inhibitor CCC which effectively reduces leaf and stem growth in these grasses (Heide et al. 1985, Fig. 5), significantly enhanced primary induction, especially under marginal conditions (Fig. 6, Tables 2-3). These results may have interesting practical applications for increasing flowering and seed production under field conditions. At high latitudes species like *B. inermis* and *P. arundinacea*, which have an obligatory SD requirement for primary induction, tend to get a short and suboptimal induction period in the autumn. This is probably a main reason for the low seed yields reported for these species in Alaska and Norway (e.g. Klebesadal 1970; Berg 1982; Østrem 1988). Autumn application of CCC in seed production leys in order to lower the GA content of the plants before the onset of SD might extend the effective induction period and increase flowering and seed yield. In *Poa* pratensis such autumn application of CCC increased the number of panicles in cvs. Fylking and Merion, but had no effect in the dwarf cv. Nugget. Autumn spraying with GA_3, on the other hand, reduced flowering below control levels (Buettner et al. 1976). Ongoing field tests with autumn application of CCC have given promising seed yield increases in both *B. inermis* and *P. arundinacea* (Jonassen 1994). Correct timing of such applications and their proper combination with other autumn treatments are important for optimizing the effect and should therefore be subject to further studies.

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Pure stand establishment of *Poa pratensis* L. for seed production: sowing rates and sowing methods

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In a sowing rate experiment at Lillehammer (62°N), seed yield of *Poa pratensis* cv. 'Holt' was unaffected in the first ley year, but was higher at 2.5 and 5.0 kg ha^{-1} than at 10.0, 15.0 and 20.0 kg ha^{-1} in the second ley year. In experiments on sowing rates (2.5, 5.0 and 10.0 kg ha^{-1}) and sowing methods (broadcasting, row spacing 16.5 cm, row spacing 33.0 cm + carbon-banding) carried out at Landvik, Grimstad (58°N) in cvs. 'Lavang' and 'Leikra', it was found that 2.5 kg ha^{-1} gave the highest seed yield in fields with a rapid and uniform germination, but this rate was inferior to 5.0 and 10.0 kg ha^{-1} in fields with delayed crop emergence and a high pressure of *Poa annua* L. and *Alopecurus geniculatus* L. On average, a rate of 5.0 kg ha^{-1} gave the highest panicle number in 'Lavang', whereas in 'Leikra' the seed yield was lower at 10.0 kg ha^{-1} than at lower rates. As compared with the other sowing methods, 33.0 cm row spacing + carbon-banding generally decreased weed contamination and increased seed yield in the first ley year in 'Lavang', but the method had a similar effect in 'Leikra' only in a field with a high pressure of weeds. It was found that the average weed contamination in both cultivars was higher at 2.5 kg ha^{-1} than at higher sowing rates.

Key words: *Alopecurus geniculatus* L., carbon-banding, field germination, *Poa annua* L., seed yield, yield components.

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In perennial grasses, seed production is normally stimulated by lower plant densities than used in the production of forage (Jonassen 1980). A moderate number of plants per unit area results in less competition for space, light, water and nutrients among the grass tillers. This is crucial, both in autumn when each individual tiller must reach a critical size in order to respond to flower induction stimuli (Cooper & Calder 1964; Calder 1966; Meijer 1984), and in the spring and early summer when many induced tillers tend to succumb in the competition for light during stem elongation (Meijer & Vreeke 1988).

In experiments carried out in Denmark, the optimal density in seed crops of *Phleum pratense* L., *Festuca pratensis* Huds., *Lolium perenne* L. and *Dactylis glomerata* L. was

stipulated as 50-100 plants m^{-2} (Nordestgaard 1975a, 1975b, 1977, 1979). An optimal sowing rate can be calculated from these figures and information about seed weight, but estimates for field germination always remain an uncertain factor in such calculations. In the case of *Poa pratensis* L., a field germination of merely 10-20% may be the rule rather than the exception (Nordestgaard 1983).

The worst obstacles to Norwegian seed production of *Poa pratensis* are the grass weeds *Poa annua* L. and *Alopecurus geniculatus* L., which are impossible to clean out during seed processing. During the past 10 years, approximately 50% of all *Poa pratensis* seed crops have been rejected due to more than 1.0% (w/w) contamination by these weeds (The Norwegian State Seed Testing Station, pers. comm.).

No selective herbicides are presently approved for the control of *Poa annua* and *Alopecurus geniculatus* in Norwegian seed crops of *Poa pratensis*. The carbon-banding technique (Lee 1973), successfully introduced in Oregon, USA (Youngberg 1980), represents an alternative way of controlling weed under such circumstances. Initial Norwegian experiments on severely infested soils demonstrated that carbon-banding reduced the contamination by *Poa annua* and *Alopecurus geniculatus* from 1394 to 100-200 seeds per gram seed yield (Synnes 1986). Though this reduction was not sufficient to meet the certification requirements, further research with carbon-banding on moderately infested soils seemed justified.

In addition to herbicide applications, biological methods must be utilized in order that the seed crop can compete more efficiently against weeds. Earlier experiments with *Poa pratensis* demonstrated that various dates of autumn cutting exerted a major influence on weed contamination in the subsequent seed production year (Aamlid 1993). Higher sowing rates raised the purity percentage in precleaned seed of *Phleum pratense*, *Festuca pratensis*, *Lolium perenne* and *Dactylis glomerata* (Nordestgaard 1975a, 1975b, 1977, 1979). In forage trials, Johansen & Synnes (1992) found that various grass species competed more effectively against *Poa annua* L. when sown in a cross at a rate of 35 kg ha^{-1} than when sown in one direction at 25 kg ha^{-1}. Except for one field with poor germination caused by drought, broadcasting at a rate of 35 kg ha^{-1} gave the best weed control in these trials.

The objective of the present research was to find a sowing rate and a sowing method in a pure stand establishment of *Poa pratensis* that would produce high seed yields with an acceptable level of purity. The main trials were carried out at Landvik Research Station (58°N) during 1988 through 1992, but this article also includes earlier unpublished results from a sowing rate experiment conducted at Lillehammer (62°N) in 1980-82.

MATERIALS AND METHODS

Sowing rate experiment, Lillehammer 1980-82

Poa pratensis 'Holt' was sown without a cover crop on a moraine soil at Nordre Haave farm on 16 June 1980. The four-replicate randomized complete block design included five sowing rates: 2.5, 5.0, 10.0, 15.0 or 20.0 kg ha^{-1}. Broadleaved weeds were controlled by bentazone on 25 July in the sowing year and MCPA on 18 May in ley year 1. Foliage was cut and removed in late August in the sowing year, but not in ley year 1. Nitrogen applications were as follows:

Year	kg N ha^{-1}	Date	Type
Sowing year (1980)	40	Before sowing	NPK 16-7-12
	39	25 Aug.	$Ca(NO_3)_2$
Ley year 1 (1981)	48	25 Apr.	NPK 16-7-12
	62	2 Sep.	$Ca(NO_3)_2$
Ley year 2 (1982)	40	21 Apr.	NPK 16-7-12

Plots were harvested with a field plot combine on 3 August 1981 and 30 July 1982. The seed was cleaned, but not analysed for purity. Recordings included crop coverage on 30 April 1981 and the lodging percentage before harvest in 1981 and 1982.

Experiments on sowing rate/sowing method, Landvik 1988-92

Separate experiments in two cultivars, 'Lavang' and 'Leikra', were established without cover crop on 19 May 1988 and 8 May 1989. With the exception of the 1988 planting of 'Leikra', which took place on a sandy loam (57% sand, 34% silt, 9% clay), all plantings were situated on silt loams (29-33% sand, 54-60% silt, 13-16% clay).

In 1989, field emergence of 'Leikra' was very slow, and, as an insurance, one additional field was sown not far from the first one on 2 June. During June and July, germination became acceptable in either field, however, and it was therefore decided to keep both for the determination of seed yield and other parameters. The fields of 'Leikra' sown on 8 May and 2 June 1989 were designated A and B, respectively.

The experimental plan included two factors which were completely randomized into each of three blocks (replicates):

Sowing rates:	Sowing methods:
A. 2.5 kg ha^{-1}	X. Drilling at 16.5 cm row spacing
B. 5.0 kg ha^{-1}	Y. Carbon-banding at 33.0 cm row spacing
C. 10.0 kg ha^{-1}	Z. Broadcasting

Sowing depth on drilled and carbon-banded plots was 0.5-1.0 cm. Carbon-banding implied the application of a slurry of charcoal at a rate of 36 kg ha^{-1} in 3 cm wide bands over each drill, followed by spraying with simazine at 750 g a.i. ha^{-1}. Since the sandy soil selected for 'Leikra' in 1988 was practically free of grass weeds, this particular field was drilled at a row spacing of 33.0 cm without carbon-banding. Broadleaved weeds were always controlled by application of bromfenoxim (1500 g a.i. ha^{-1}) 3-4 weeks after sowing.

Both in the sowing year and in subsequent ley years fields were fertilized with $Ca(NO_3)_2$ at a rate of 50 kg N ha^{-1} in September. In the beginning of April, a NPK fertilizer was applied at a rate of 30 kg N/ha in the first ley year and 50 kg N ha^{-1} in the second and third ley years.

The fields were not defoliated in the year of establishment, but in the ley years, stubble and aftermath were cut to 5 cm and removed before the application of nitrogen in September.

The percentage crop coverage was always determined in the spring of ley year 1. Recordings before seed harvest generally included lodging and panicle numbers in a frame 60 cm x 60 cm. Seed numbers per panicle were calculated from seed yield and the other

yield components.

At 30-35% seed water content, the seed crops were threshed directly using a field plot combine. The straw was weighed and usually rethreshed after approximately one week's curing. After seed drying and cleaning, seed samples were analysed for purity and contamination by *Poa annua* and *Alopecurus geniculatus* at The Norwegian State Seed Testing Station. Since 'Leikra' was sown in a virtually clean soil in 1988, the determination of weed content was omitted for this particular field. Analyses for thousand seed weight and germination were performed in the seed laboratory at Landvik Research Station. Thousand seed weight, weed contamination and germination data presented in this report are weighed means for the first and second harvests.

Statistical analyses

For the field experiment at Lillehammer, separate analyses of variance were performed for every parameter in each ley year. For the main experiments at Landvik, crop coverage in the first ley year (Table 2, Fig. 1) and seed yields in all ley years (Tables 3-6, Fig. 2) were analysed separately, but for the other parameters only one overall analysis was conducted for each cultivar, testing the main effects of sowing rate and sowing method as well as their interaction against a common, pooled error. Significance levels $p<0.05$, $0.01<p<0.05$ and $p<0.001$ were indicated by *, ** and ***, respectively, and for some non-significant tendencies, probability values were supplied. Significant differences were separated by $LSD_{0.05}$.

RESULTS

Sowing rate experiment at Lillehammer 1980-82

Sowing rate had no significant influence on crop coverage or seed yield in the first ley year (Table 1). In ley year 2, sowing rates of 10 kg ha^{-1} and higher produced significantly less seed than sowing rates at 2.5 and 5.0 kg ha^{-1}, which were not different. The lodging percentage was not affected by sowing rate.

Table 1. Crop coverage (%) in the spring of ley year 1 and seed yield (kg ha^{-1} of cleaned seed, 14% water content) in ley years 1 and 2 in a sowing rate experiment in *Poa pratensis* L. 'Holt' established at Lillehammer in 1980.

Sowing rate kg ha^{-1}	Crop coverage	Seed yield Ley year 1	Seed yield Ley year 2
2.5	61	470	256
5.0	56	423	267
10.0	64	483	204
15.0	71	464	169
20.0	70	429	145
Sign.	ns	ns	***
$LSD_{0.05}$	-	-	50

Experiments on sowing rates and sowing methods at Landvik 1988-92

Crop coverage in spring, ley year 1

The field germination in 1988 was rapid and uniform, and sowing rate had no effect on crop coverage in 'Leikra' and only a small effect in 'Lavang' (Table 2). By contrast, increases in sowing rates clearly enhanced crop coverage in all fields sown in 1989.

Table 2. Effect of sowing rate on crop coverage (%) in the spring of ley year 1 in *Poa pratensis* L. 'Lavang' and 'Leikra' established at Landvik in 1988 and 1989. Means of three sowing methods.

Sowing year	Sowing rate (kg ha^{-1}) 2.5	5.0	10.0	Sign.	$LSD_{0.05}$
		Lavang			
1988	85	92	93	**	5
1989	48	65	82	***	12
Mean	67	79	87	*	12
		Leikra			
1988	91	95	93	ns(p=0.18)	-
1989A	36	68	82	***	7
1989B	63	71	73	*	7
Mean	63	78	83	*	13

In field A of 'Leikra' sown in 1989, the average crop coverage was 73, 63 and 51% on narrow-drilled, carbon-banded and broadcast plots, respectively ($LSD_{0.05}=7$, data not shown in table). A significant interaction indicated that crop coverage in this particular field fell more dramatically with decreasing sowing rates on broadcast plots than on drilled plots (Fig.1). On average for all fields, the effect of sowing method on crop coverage was not significant in either 'Lavang' or 'Leikra'.

Seed yields

Increasing sowing rate diminished seed yields in the first and second ley years in both cultivars established in 1988 (Tables 3 and 5). In contrast, a sowing rate of 2.5 kg ha^{-1} produced significantly less seed than rates of 5.0 and 10.0 kg ha^{-1} in the first two ley years of 'Lavang' and 'Leikra' (field A) sown in 1989. In all fields, seed production of 'Leikra' in ley year 3 tended to be stimulated by the lowest sowing rate.

Seed yields of 'Lavang' were augmented by 33.0 row spacing + carbon-banding in both fields in the first ley year (Table 4). In 'Leikra', carbon-banding was superior to narrow drills and broadcasting only in field A established in 1989 (Table 6).

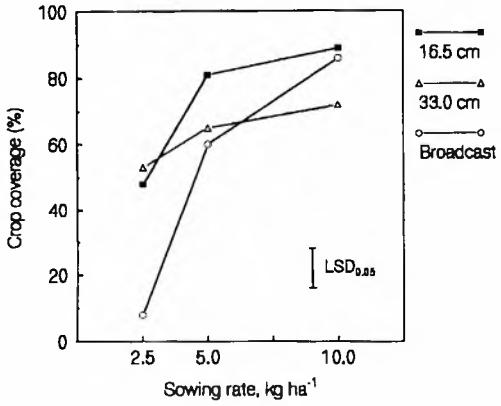

Fig. 1. Crop coverage of 'Leikra' in the spring of ley year 1 as influenced by sowing rates and sowing methods. (Field A sown in 1989. The 33.0 cm row distance was combined with carbon banding).

Table 3. Effect of sowing rate on seed yield (kg ha^{-1}, 100% purity, 14% water content) of 'Lavang' in ley years 1, 2 and 3 in two experimental fields at Landvik. Means of three sowing methods.

Sowing year	Ley year	Sowing rate (kg ha^{-1}) 2.5	5.0	10.0	Sign.	$LSD_{0.05}$
1988	1	1567	1500	1357	*	145
	2	529	460	389	**	76
	3	251	245	201	ns	-
1989	1	463	704	710	***	78
	2	480	616	614	*	95
Mean		658	705	654	ns	-

Table 4. Effect of sowing method on seed yield (kg ha^{-1}, 100% purity, 14% water content) of 'Lavang' in ley years 1, 2 and 3 in two experimental fields at Landvik. Means of three sowing rates.

Sowing year	Ley year	Sowing method Drilled 16.5 cm	Carbon-banded 33.0 cm	Broad-cast	Sign.	$LSD_{0.05}$
1988	1	1350	1590	1484	*	145
	2	432	459	487	ns	-
	3	241	260	197	ns	-
1989	1	557	767	553	***	78
	2	543	609	558	ns	-
Mean		625	737	656	*	79

Table 5. Effect of sowing rate on seed yield (kg ha^{-1}, 100% purity, 14% water content) of 'Leikra' in ley years 1, 2 and 3 in three experimental fields at Landvik. Means of three sowing methods.

Sowing year	Ley year	Sowing rate (kg ha^{-1}) 2.5	5.0	10.0	Sign.	$LSD_{0.05}$
1988	1	671	499	386	***	97
	2	398	288	191	***	45
	3	199	168	150	ns(p=0.07)	-
1989A	1	290	467	427	***	60
	2	619	713	732	**	71
	3	172	156	142	ns(p=0.10)	
1989B	1	444	443	425	ns	-
	2	426	400	374	ns(p=0.06)	-
	3	165	139	117	*	38
Mean		376	364	327	*	39

Table 6. Effect of sowing method on seed yield (kg ha^{-1}, 100% purity, 14% water content) of 'Leikra' in ley years 1, 2 and 3 in three experimental fields at Landvik. Means of three sowing rates.

Sowing year	Ley year	Sowing method Drilled 16.5 cm	Carbon-banded 33.0 cm	Broad-cast	Sign.	$LSD_{0.05}$
1988	1	530	519	507	ns	-
	2	283	306	288	ns	-
	3	173	169	175	ns	-
1989A	1	378	461	346	**	60
	2	681	734	648	ns(p=0.06)	-
	3	147	184	139	**	28
1989B	1	440	436	437	ns	-
	2	396	397	407	ns	-
	3	120	155	146	ns	-
Mean		350	373	344	ns	-

In both 'Lavang' (Fig. 2) and field A of 'Leikra' (data not shown) sown in 1989, the lowest sowing rate had a more harmful effect on seed yield in broadcast plots and in plots drilled at 16.5 cm row spacing than in plots carbon-banded at 33.0 cm. (Interactions significant at $p<0.05$ and $p<0.01$, respectively).

Yield components

The effect of sowing rate on panicle number closely reflected the effects on seed yields: the rates 2.5 and 5.0 kg ha^{-1} were generally superior to 10.0 kg ha^{-1} in the fields established in 1988, and 2.5 kg ha^{-1} was inferior to higher sowing rates in the first and second ley years in the fields established in 1989 (details not shown). On average for all fields, sowing rate had no influence on panicle number in 'Leikra', whereas 5.0 kg ha^{-1} resulted in the

highest panicle number in 'Lavang' (Table 7). Sowing method had no overall effect on panicle number in either cultivar (Table 8).

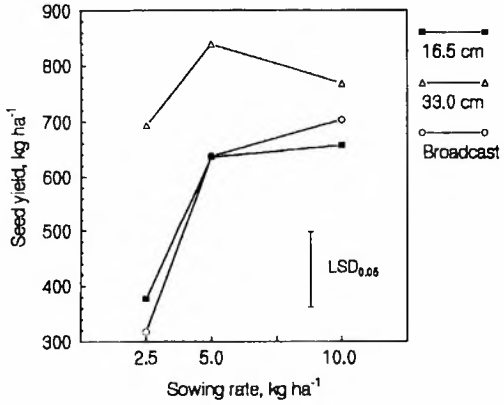

Fig. 2. Seed yield of 'Lavang' (100% purity, 14% water content) in ley year 1 as influenced by sowing rates and sowing methods. (Field sown in 1989. The 33.0 cm row distance was combined with carbon banding).

Table 7. Effect of sowing rate on panicle number, seed number per panicle, thousand seed weight, content of *Poa annua* L. and *Alopecurus geniculatus* L. in precleaned seed, speed of germination, germination capacity, straw yield and the lodging percentage at harvest in 'Lavang' and 'Leikra' at Landvik. Means of three sowing methods.

Character	Number of harvests	Sowing rate (kg ha^{-1}) 2.5	5.0	10.0	Sign.	$LSD_{0.05}$
			Lavang			
Panicle number per m^2	5	1458	1686	1483	*	196
Seed number per panicle	5	146	137	146	ns	-
Thousand seed weight (mg)	5	299	303	304	ns	-
Poa annua (%)	5	5.7	2.4	1.1	**	2.7
Alopecurus geniculatus (%)	5	1.3	0.8	0.6	*	0.5
Speed of germination	5	81	81	81	ns	-
Germination capacity	5	89	88	89	ns	-
Straw yield (kg/ha)	4	4041	4023	4081	ns	-
Lodging (%)	5	3	6	6	ns	-
			Leikra			
Panicle number per m^2	9	725	737	682	ns	-
Seed number per panicle	9	205	186	189	ns(p=0.08)	-
Thousand seed weight (mg)	9	271	271	270	ns	-
Poa annua (%)	6	0.9	0.4	0.3	***	0.3
Alopecurus geniculatus (%)	6	0.4	0.2	0.2	**	0.1
Speed of germination	6	60	61	59	ns	-
Germination capacity	6	83	82	83	ns	-
Straw yield (kg/ha)	8	5879	5704	5663	ns	-
Lodging (%)	9	42	41	44	ns	-

Table 8. Effect of sowing method on panicle number, seed number per panicle, thousand seed weight, content of *Poa annua* L. and *Alopecurus geniculatus* L. in precleaned seed, speed of germination, germination capacity, straw yield and the lodging percentage at harvest in 'Lavang' and 'Leikra' at Landvik. Means of three sowing rates.

Character	Number of harvests	Sowing method			Sign.	$LSD_{0.05}$
		Drilled 16.5 cm	Carbon-banded 33.0 cm	Broad-cast		
			Lavang			
Panicle number per m^2	5	1519	1609	1499	ns	-
Seed number per panicle	5	136	147	146	ns	-
Thousand seed weight (mg)	5	306	305	295	*	9
Poa annua (%)	5	3.2	2.1	3.8	ns	-
Alopecurus geniculatus (%)	5	0.8	0.7	1.2	ns(p=0.07)	-
Speed of germination	5	81	82	80	ns	-
Germination capacity	5	89	90	88	**	1
Straw yield (kg/ha)	4	3725	3973	4446	*	390
Lodging (%)	5	2	10	3	ns(p=0.07)	-
			Leikra			
Panicle number per m^2	9	707	734	704	ns	-
Seed number per panicle	9	192	197	191	ns	-
Thousand seed weight (mg)	9	270	274	268	*	4
Poa annua (%)	6	0.5	0.4	0.6	ns	-
Alopecurus geniculatus (%)	6	0.2	0.2	0.3	ns	-
Speed of germination	6	60	61	59	ns	-
Germination capacity	6	83	83	82	*	1
Straw yield (kg/ha)	8	5843	5880	5523	ns	390
Lodging (%)	9	43	44	40	ns	-

On average for all fields, an increase in sowing rate tended to decrease the (calculated) seed number per panicle in 'Leikra' (Table 7), but had no influence in 'Lavang'. Seed number per panicle was not affected by sowing method in either cultivar.

In 'Lavang', thousand seed weight was lower on broadcast plots than on drilled plots, and in 'Leikra' plots drilled at 33.0 cm row spacing produced heavier seeds than broadcast plots and plots drilled at 16.5 cm (Table 8). Thousand seed weight was not influenced by sowing rate in either cultivar (Table 7).

Weed contamination

Increased sowing rate significantly reduced the content of *Poa annua* and *Alopecurus geniculatus* in both cultivars (Table 7). Though the overall analysis revealed no significant effect of sowing method on weed content (Table 8), 33.0 cm row spacing + carbon banding improved weed control in ley year 1 of 'Lavang' sown in 1988 and of 'Lavang' and 'Leikra' (field A) sown in 1989. In these fields the total contamination by *Poa annua* + *Alopecurus geniculatus* was as follows (w/w, %):

	Drills 16.5 cm	Carbon-banding 33.0 cm	Broadcast
Lavang 1988	1.4	0.7	2.0
Lavang 1989	12.6	7.0	14.5
Leikra 1989A	1.6	1.0	1.7

Germination
In 'Lavang' germination capacity was significantly lower on broadcast than on drilled plots (Table 8). Otherwise, neither speed of germination nor germination capacity was affected by the treatments in either cultivar.

Straw yield
Whereas sowing method had no impact on straw yield in 'Leikra', broadcast plots generally produced more straw than drilled plots in 'Lavang' (Table 8), but there was no effect at all of sowing rate on this character.

Lodging
In ley year 1 of 'Lavang' sown in 1988, lodging was more severe on plots drilled at 33.0 cm row spacing than on broadcast plots or plots drilled at 16.5 cm. Otherwise, no lodging was ever observed in 'Lavang'. Lodging occurred in all fields of 'Leikra', but this character was not influenced by treatments.

DISCUSSION

The main experiments at Landvik fully underscore the problem of finding a reliable estimate for field germination in *Poa pratensis*: in 1988 emergence was rapid and uniform; in 1989 it was incomplete and delayed to such an extent that a second field was sown in one of the cultivars.

The two most important conditions for successful establishment of small-seeded grasses are adequate soil moisture and temperature. In the experiments at Landvik, total rainfall in the period from two weeks before until four weeks after sowing was always in the range 27-36 mm, which should not have imposed any limitation on seed imbibition and germination. On the other hand, the great difference in field emergence, and thus crop coverage in the spring of the first ley year (Table 2), can most likely be attributed to the average air temperature during the first four weeks after sowing: 13.7°C in 1988 as opposed to only 10.6°C in 1989 ('Lavang' and field A of 'Leikra'). In 'Leikra', seedbed temperature probably differed even more than this, as the 1988 crop was sown on a sandy soil that was much warmer than the silt used in 1989. Field B was sown later when the average air temperature was 14.3°C during the first four weeks after sowing, but, again, this crop was sown in a fairly cool soil. It has earlier been documented that *Poa pratensis* L. germinates faster on sandy than on silt soils (Aamlid 1991).

Depending on the success of establishment, the present experiments fall into three categories with regard to sowing rate: for both trials sown in 1988, 2.5 kg ha^{-1} was more than adequate to obtain the desired plant number; hence, the problem of sward densification showed up already in ley year 1. The experiment sown at Lillehammer in 1980 and the second crop of 'Leikra' sown at Landvik in 1989 (field B) had an intermediate establishment, and the advantage of lower sowing rates did not appear until ley year 2. The third category includes 'Lavang' and field A of 'Leikra' sown in 1989, in which the lowest sowing rate failed to create a sufficient number of plants during the sowing year. However, even for one of the fields within the category, there was a tendency for the seed yield to decrease with increased sowing rate in ley year 3.

In sowing rate experiments conducted by Jonassen (1980) high seed yields of *Festuca pratensis*, *Festuca rubra*, *Dactylis glomerata* and *Agrostis capillaris* were obtained at sowing rates in the range 1-3 kg ha^{-1}. In Danish and Dutch trials with *Poa pratensis* L., seed yields diminished as sowing rates exceeded 10 and 12 kg ha^{-1}, respectively, but differences between rates below these thresholds were not significant (Nordestgaard & Larsen 1974; Meijer 1984). Kansanen et al. (1982) reported higher seed yields at 4 kg ha^{-1} than at 8 kg ha^{-1}. The present results suggest 5 kg ha^{-1} as an appropriate sowing rate for practical pure stand establishment of *Poa pratensis* in Norway. This rate is sufficient to create enough plants in relatively unfavourable seedbeds; on the other hand, it might be overoptimal for warm, conducive soils with a low weed content.

The optimal sowing rate also depends on sowing method. Unfavourable seedbeds or unpredictable precipitation generally makes broadcasting less reliable than drilling, and a higher sowing rate may be necessary (Figs. 1 and 2). Similar results have been demonstrated in forage trials with *Phleum pratense* (Pestalozzi 1960). Fulkerson (1959) recommended that the sowing rate in seed production of *Dactylis glomerata* should be lower at wide than at narrow row spacing, and this is in agreement with the present material.

In Oregon a row spacing of 30-36 cm is commonly used in seed production of *Poa pratensis* (Youngberg 1980). By contrast, row spacing of more than 15 cm is rarely used in Denmark, although Johansen (1970) found that seed yields in the second and third ley years improved slightly when the row spacing was widened from 15 cm to 30 cm. Canode (1968), Johansen (1970) and Rampton et al. (1971) reported lower seed yields when the row spacing was increased beyond 60 cm, 30 cm and 30 cm, respectively. In two out of three trials in Norway, the total seed yield for a three-year ley period was higher on plots broadcast at 20.0 kg/ha^{-1} than on plots sown at a rate of 5.0 kg/ha^{-1} in 60 cm rows (Schjelderup 1982).

In the present material, the effect of wide rows (33.0) cannot be separated from the effect of carbon-banding with the exception of 'Leikra' sown in 1988. In both cultivars sown in May 1989, *Poa annua* and *Alopecurus geniculatus* appeared not only as restraints to seed lot purity, but also as competitors for light, water and nutrients, and there is little doubt that the higher seed yields at a row spacing of 33.0 cm + carbon-banding in ley year 1 in these fields were mainly due to better weed control. At lower weed pressure, a row spacing of 33.0 cm seemed advantageous to seed yield in 'Lavang', but not in 'Leikra'; this can probably be attributed to earlier and more vigorous rhizome formation in the former cultivar (Aamlid 1992).

Despite the benefit of carbon-banding in ley year 1, the method did not control weeds for the ley period as a whole (Table 8). The open stand created by wide row spacing probably offered more opportunity for weeds to germinate as the soil herbicide (in this case simazine) was degraded, hence, there was little difference between the sowing methods as to weed contamination in ley years 2 and 3.

Unlike Johansen & Synnes's forage trials (1992), it was found that in the present seed production experiments broadcasting never improved weed control. This must have been because Johansen & Synnes (1992) used higher sowing rates (20-35 kg ha^{-1}) and species with faster field emergence than *Poa pratensis* L. Generally, the demand for weed control is much higher and more accurate in the production of seed than in the production of forage, and the present results clearly dispute broadcasting as a measure to improved seed-lot purity.

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Dry matter production and botanical composition of monocultures and mixtures of meadow fescue (*Festuca pratensis* Huds.) and timothy *(Phleum pratense* L.) in field experiments at three locations in northern Norway 1984-89

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Botanical composition and dry matter production of monocultures and three different mixtures (30:70, 50:50 and 70:30, by seed weight) of meadow fescue (*Festuca pratensis* Huds.) and timothy *(Phleum pratense* L.) were studied in field experiments over a period of five years at three locations in northern Norway. Meadow fescue generally displaced timothy in all mixtures, probably due partly to its higher competitive ability than timothy and partly to differing overwintering capability. Dicotyledons and native grasses gradually invaded the fields, probably reflecting winter damage which may have caused gaps and thinning out of the sown grasses in the swards. Monocultures of timothy had a higher proportion of dicotyledons and native grasses than the other stands. Total yields tended to be higher in the mixtures than in the monocultures of both species, but the differences between mixtures and monocultures of meadow fescue were not statistically significant. However, the annual variation in dry matter production caused by overwintering conditions and summer weather was higher than the variation between both the locations and the types of stands.

Key words: Botanical composition, competition, dry matter production, *Festuca pratensis*, overwintering, *Phleum pratense*.

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Meadow fescue (*Festuca pratensis* Huds.) increased in popularity as a forage grass during the 1980s among farmers in the northern regions when a new variety, Salten (67°N lat.), which was well adapted to the harsh winter conditions of northern Norway (Andersen 1971) became available. Meadow fescue is more resistant to low temperature fungi (Årsvoll 1977;

Vestman 1978) and is also considered to be more competitive against weeds than timothy (*Phleum pratense* L.) (Vik 1955; Grønnerød 1988). In mixtures with timothy, meadow fescue could therefore stabilize the yields over time. In some studies, meadow fescue is observed to establish slowly, but gradually it becomes predominant in the mixture with timothy (Bø 1970; Skaare 1970; Jetne 1980). These changes in the botanical composition may be related both to differences in overwintering capability and to interspecific competition.

In 1983, a series of 15 experiments was initiated at locations covering the region of northern Norway where yield production and changes in the botanical composition were observed over time in monocultures and binary mixtures of meadow fescue, timothy and smooth meadow grass (*Poa pratensis* L.). The aim of the study was to identify the most persistent and highest yielding stands for the different locations. As part of a study on competition between timothy and meadow fescue we report here on the change in botanical composition and dry matter production in monocultures and mixtures of timothy and meadow fescue in five experiments at three locations representing subarctic coastal and continental climates.

MATERIALS AND METHODS

Growing conditions and measurements

The field trials were established at Svanhovd, Pasvik (two fields, a and b), Flaten, Alta (two fields, c and d) and at Holt Research Station, Tromsø (field e) (Table 1). The air temperatures and precipitation during the experimental periods are shown in Fig. 1.

Plots measuring 1.5 x 5.0 m were sown with timothy (T) (cv. Engmo, origin 69°N lat.) and meadow fescue (F) (cv. Salten, origin 67°N lat.) to establish monocultures and 30:70, 50:50 and 70:30 mixtures by seed weight (30 kg seed/ha, in total). The corresponding numbers of seeds per m^{-2} were approximately 2000 T : 1000 F, 3000 T : 750 F and 4000 T : 500 F.

In the year of establishment, the fields were fertilized with 70 kg nitrogen (N) ha^{-1}, 30 kg phosphorus (P) ha^{-1} and 8 kg potassium (K) ha^{-1} and no measurements were undertaken.

Table 1. Location, soil and climate of the experimental field

Location	Field	Lat.	Long.	Climate	Soil type	Experimental period
Svanhovd (Pasvik)	a	69°27'N	30°30'E	Subarctic/continental	Silt loam above silty clay	1984-86
	b	"	"	"	Peat above silty clay	1986-89
Flaten (Alta)	c	69°56'N	23°22'E	Subarctic/continental	Silt loam above silty clay-loam/silty clay	1985-88
	d	"	"	"	"	1986-89
Holt (Tromsø)	e	69°40'N	18°56'E	Subarctic/coastal	Loamy sand	1985-88

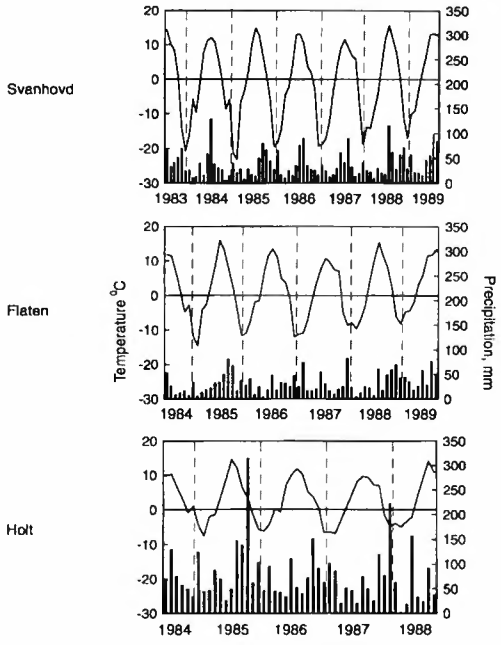

Fig. 1. Average monthly air temperature (—) and precipitation (bars) during the experimental periods at Svanhovd (Pasvik meterological station for temperatures, and Bjørnesund meteorological station for precipitation), Flaten (October-April: Elvebakken meteorological station, May-September: Flaten) and Holt (Tromsø meteorological station). From the Norwegian Meteorological Institute (1983-89).

The fields at Holt and Flaten were cut twice per growing season and fertilized each spring with 98 kg N ha^{-1}, 42 kg P ha^{-1} and 112 kg K ha^{-1}, and after the first harvest with 54 kg N ha^{-1}, 9 kg P ha^{-1} and 45 kg K ha^{-1}. The first cut was taken when timothy was at heading stage and the second cut was taken at the end of August. The fields at Svanhovd were cut once per growing season and fertilized in spring with 112 kg N ha^{-1}, 48 kg P ha^{-1} and 120 kg K ha^{-1}. In 1987 and 1988, field b at Svanhovd was cut twice and hence received the same amount of fertilizers as the fields at Holt and Flaten.

The harvested material was weighed and dry matter was determined by drying a subsample of about 500-1000 g for 48 h at 60°C. Before harvesting, the botanical composition of the plots was assessed visually as the cover of meadow fescue, timothy, smooth meadow grass, other grasses and dicotyledonous species.

Experimental design and statistics

The experiments were arranged in a randomized complete block design with three replicates. Analyses of variance were carried out on the yield data using the GLM procedure of the statistical package SAS (SAS Institute, 1987). Tukey's Studentized range test was performed on all main effects. Correlations on yield data and temperature were performed using the CORR procedure of SAS.

RESULTS

Yields

The yields varied with location, year and type of stand (Tables 2 and 3). On average, the highest yields were obtained in field d at Flaten, and the lowest in field a at Svanhovd (Table 2). In the fields observed up until 1988 and 1989, the dry matter production was significantly lower in 1987 and 1988 than in the other years ($p<0.05$). There was a significant correlation ($p<0.0001$, $r^2=0.53$) between dry matter production of the second cut and the average summer (May-September) temperature of all locations.

Table 2. Total dry weights (kg ha^{-1}) per year of the five experiments. Values are averaged over stands ± S.E

Location		Year 1984	1985	1986	1987	1988	1989	All years[1]
Svanhovd	Field a	8055 ±244	5480 ±283	8004 ±279	-	-	-	7180c
"	Field b	-	-	7936 ±222	6310 ±222	5210 ±119	10127 ±213	7396c
Flaten	Field c	-	8557 ±172	8771 ±143	6131 ±126	5639 ±152	-	7275c
"	Field d	-	-	9145 ±138	6554 ±169	7946 ±215	10997 ±293	8661a
Holt	Field e	-	8705 ±231	9275 ±174	6703 ±119	7032 ±231	-	7921b
All locations[2]		8055c	7581c	8626bc	6425d	6457d	10562a	

Means over years[1] and locations[2] which are followed by the same letter do not differ significantly ($p>0.05$) based on Tukey's Studentized range test

Table 3. Total dry weights (kg ha^{-1}) of the monocultures and mixtures of the five experiments. Values are the average over the experimental periods ± S.E

Stand		Svanhovd Field a	Field b	Flaten Field c	Field d	Holt Field e	All locations[1]
Timothy monoculture	(T)	6674 ±548	7482 ±561	6968 ±540	8040 ±501	7425 ±446	7352b
Meadow fescue monoculture	(F)	7177 ±491	7036 ±575	7363 ±427	8728 ±484	7969 ±335	7680ab
T 30 : F 70		7374 ±644	7613 ±618	7569 ±409	9011 ±541	8248 ±383	7994a
T 50 : F 50		7189 ±508	7412 ±576	7328 ±435	8778 ±584	8010 ±396	7772a
T 70 : F 30		7483 ±524	7437 ±659	7145 ±432	8747 ±572	7952 ±344	7767a

Means over locations[1] which are followed by the same letter do not differ significantly ($p>0.05$) based on Tukey's Studentized range test

The highest yields were reached in the mixtures of timothy and meadow fescue at all locations (Table 3). Generally, the mixtures of 30% timothy and 70% meadow fescue ranked first, whereas the lowest yields were obtained in the monocultures of both species. However, the differences in yield between meadow fescue in monoculture and the different mixtures were not significant.

There were no significant differences in the dry matter production between the stands at the first harvest (data not shown). However, regrowth of meadow fescue in monocultures after the first harvest was significantly higher than regrowth of the other stands ($p<0.05$).

Botanical composition

Generally, there was a considerable increase with time in the proportion of meadow fescue at the expense of timothy in all mixtures between timothy and meadow fescue (Fig. 2). Even in the mixtures of 70% timothy and 30% meadow fescue, the proportion of meadow fescue rapidly increased and was predominant in the mixture after two to three years. The only exception was field b at Svanhovd, where the proportions of meadow fescue and timothy fluctuated with an increase of timothy in 1987 and 1988 followed by a decrease in 1989.

At Holt and in both fields at Flaten, the proportion of sown grasses was fairly constant in all stands until 1987 (Fig. 2). However, in 1988, the proportion of non-sown grasses and dicotyledonous species increased in the timothy monocultures at Holt and in one of the fields at Flaten (field d). In the other field at the same location (field c), the proportion of dicotyledons and smooth meadow grass increased in all stands. In both fields at Svanhovd there were up to 20% dicotyledons and smooth meadow grass in all stands by the year after establishment, and the proportion increased during the experimental period.

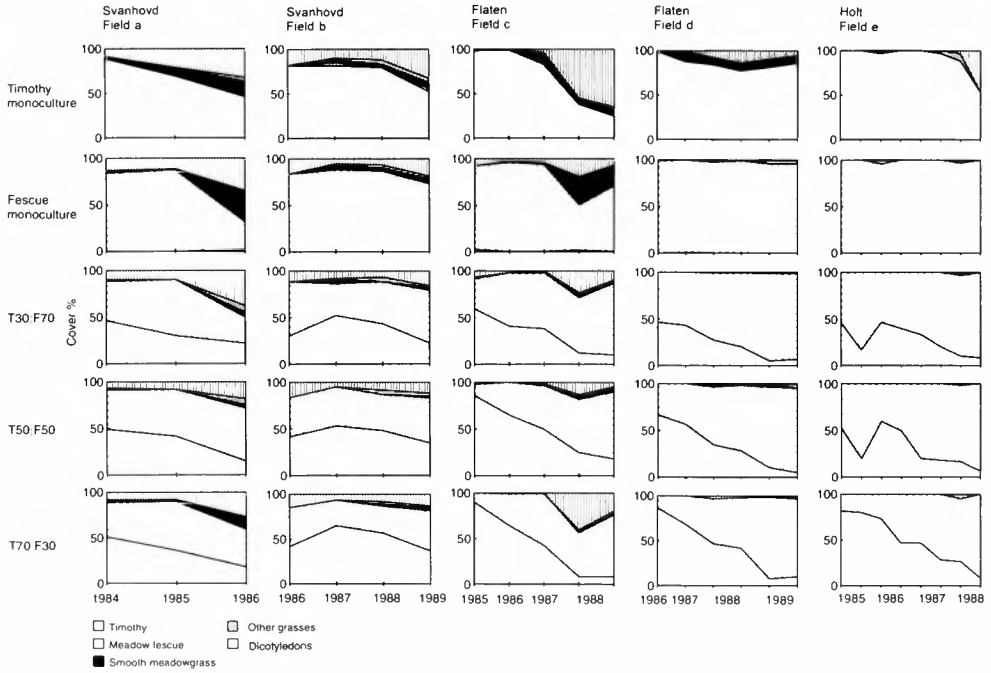

Fig. 2. Botanical composition of the monocultures and mixtures of timothy (T) and meadow fescue (F) at the different locations. The numbers following the letters indicate the seed proportion of the mixtures. Means of three replicates. The botanical composition is shown for both harvests separately from 1988 at Flaten, and in all years at Holt

DISCUSSION

Initially, timothy made up more of the mixture than the prescribed 30, 50 and 70% mixtures, partly because meadow fescue establishes slowly in the field compared with

timothy (Vik 1955; Bø 1970) and partly because of the higher number of seeds of timothy than of meadow fescue. However, the proportion of timothy clearly declined in the mixtures over the years, whereas the proportion of meadow fescue generally increased. This pattern of development in the botanical composition, which is consistent with observations of meadow fescue and timothy mixtures from other parts of Norway (Bø 1970; Skaare 1970), can be related partly to differing overwintering ability and partly to interspecific competition between meadow fescue and timothy.

Overwintering may have influenced the changes in botanical composition by thinning the sown grasses and causing gaps where indigenous grasses and dicotyledons could establish. Both abiotic factors such as ice cover and waterlogging, and biotic factors, such as low temperature fungi, frequently cause damages in grass fields in northern Norway (Andersen 1963; Andersen 1992). In field c at Flaten, smooth meadow grass and dicotyledons made up a large proportion of all stands after 1987, suggesting that the sown grasses may have been thinned out due to winter damage (Fig. 2). In both fields at Svanhovd there was an invasion of smooth meadow grass and dicotyledons from the start of the experiment, which was partly due to harsh winter condititions which made the establishment of the sown grasses difficult (Sveistrup 1992). Differing resistance to low temperature fungi and frost may also have influenced the proportion of the sown grasses. Meadow fescue is more resistant to low temperature fungi than timothy (Årsvoll 1977; Vestman 1978). Timothy, in contrast, is generally more resistant to ice encasement and frost than meadow fescue (Azzaroli & Skjelvåg 1981; Gudleifsson 1986). The winter climate both at Flaten and Svanhovd is stable and the snow cover is continuous throughout that season. As a result, attacks by fungi are a frequent problem (Årsvoll 1973). This factor may have favourable to meadow fescue in the mixture with timothy and may partly explain the higher proportion of sown grasses in the monocultures of meadow fescue than of timothy in both fields at Flaten.

At Holt, in contrast, there are sometimes temporary periods of mild weather during the winter, causing snowmelt. As a result, ice cover may develop on the ground causing conditions that are not conducive to the growth of fungi. This could explain the higher proportion of timothy in the monoculture at Holt compared with the other locations (Fig. 2). In the mixtures, however, timothy was rapidly replaced by meadow fescue in this field. This indicates that interspecific competition was the main factor causing the observed changes in the species composition of the sown grasses in this field. The methods used in this study to determine the botanical composition are not sufficient to analyse the nature and mechanisms of this competition. However, meadow fescue has also proved to be more competitive than timothy in other studies due to its higher regrowth after defoliation (Jørgensen & Junttila 1994). More detailed studies on growth and development of timothy and meadow fescue are in progress to elucidate the competitive relation between these species (Jørgensen & Nösberger 1994; Jørgensen & Junttila 1994).

The dry matter production varied with location, year and type of stand. The three locations are climatically quite different (Fig. 1), with winters being relatively mild at Holt compared with winters at Flaten and Svanhovd. Owing to higher midsummer temperatures, the average summer temperatures (May-September) during the experimental periods were higher at Flaten and at Svanhovd than at Holt, but the growing season was generally shortest at Svanhovd. These factors could explain some of the differences in yield between the locations.

The annual variation in the yields was, however, larger than the variation between the locations, and the dry matter production in the second cut was highly correlated with the average summer temperature. The dry matter production was particularly low in 1985 at Svanhovd and at all locations in 1987 and 1988. In 1985, the ground at Svanhovd was frostfree for only three weeks during the summer, and also in 1987 and 1988 the ground was frostfree for short periods (Sveistrup, pers. comm.). In 1987, the mean summer temperature of the three locations was 1.6 degrees lower than that in previous years of the experimental periods (Fig. 1), and at Holt the frost in the ground lasted until the beginning of June (Haraldsen, pers. comm.). In 1988, the snow was deep and lasted until the beginning of June at Holt, and this may have weakened the plants. Precipitation was low at Flaten in June 1988, and this combined with relatively high temperatures may have led to some drought (Fig. 1).

Generally, the mixtures tended to produce larger yields than the monocultures of both species. There is perhaps a positive relation in the seasonal pattern of growth of the species that could account for this characteristic. Timothy produces large yields at the first harvest, whereas the regrowth is low. By contrast, regrowth of meadow fescue after harvest can be large (Lambert 1962).

The dry matter production in the stands was not directly affected by the proportion of dicotyledons and unsown grasses in the fields. One explanation is that the dry matter production of the present dicotyledons and native grasses may have been similar to that of the sown grasses. This is in agreement with Nesheim (1986) who found no significant reduction in yields when the proportion of dicotyledonous species was below 50% of dry matter. Haugland (1993) found no effect of the proportion of dicotyledons on the dry matter yield of the first cut, but found a negative effect in the second cut. Schjelderup (1969) found higher yields in fields containing high proportions of native grasses than on fields dominated by timothy.

In conclusion, interspecific competition and differential winter survival of meadow fescue and timothy resulted in a considerable drop in the proportion of timothy. By contrast, meadow fescue increased its proportion of the mixture. The proportion of dicotyledons and other grasses invading the fields varied between the locations, stands and years, and reflected bad overwintering conditions. Yields varied more between years than between the locations or the stands. However, within each location, mixtures of the species tended to yield more than monocultures.

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The Apelsvoll cropping system experiment I. Background, objectives and methods

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The Apelsvoll Cropping System Experiment is aimed at comparing and developing cropping systems with regard to environmental impact, productivity, yield quality and economy. The experimental method and layout are presented and discussed here. The experimental site, its climate and history are described, and the cropping systems and their management are introduced. The lysimeter installations for measurements of nutrient and pesticide losses by runoff and leaching are key components of the experiment, and they are described in detail. An overview of the registrations which are made is also given. The soil characteristics, statistical methods and results will be presented in separate articles.

Key words: Conventional farming, cropping systems, ecological farming, economic analysis, integrated farming, lysimeter, nutrient leaching, yields, yield quality.

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The work on environmental problems in Norwegian agriculture began in earnest in the early 1970s (Lyngstad 1993), and ever since the first "Plan of Action for Reduction of Pollution in Lake Mjøsa" was presented by the Government in 1973, investigation of pollution control has been a major task in agricultural research. In recent years increasing attention has been paid to nutrient and pesticide leaching problems (Eltun 1990; Berge et al. 1994). Most of the trials dealing with nutrient leaching and runoff have been long- and short-term crop rotation and lysimeter experiments, which focused on changes in soil and yields and nutrient losses as a result of, for instance, soil tillage, fertilization and crop rotations (e.g. Rognerud et al. 1989; Uhlen 1989). With the exception of an on-farm project on development of ecological farming systems (Løes & Schmidt 1993), there have previously been no trials that have included complete cropping systems as experimental units in Norway.

In other European countries and in America the interest in the development of sustainable and environmentally sound agricultural methods has resulted in the development of cropping systems research as a discipline in agricultural research (Oberle & Keeney 1991; Vereijken 1992). Oberle & Keeney (1991) list the following objectives for agricultural systems research: to gain deeper understanding of how the components and processes of a system interact and fit together; to help solve complex problems; to identify

and rank site-specific information needs; to aid in evaluating and predicting the effects of changes in agricultural policy, management practices, production enterprises, climate and other factors.

With regard to the methodology in cropping systems research, different experimental methods have been used depending upon the main objective of the specific experiment. For modelling purposes one needs detailed information on the individual components of the system and their interactions (Johnsson et al. 1987). Both in this research and in most other kinds of systems research, traditional experimental methods are needed to obtain information about the components of the system (Oberley & Keeney 1991).

The main objective of some of the early cropping system experiments, such as the the Swiss "DOK-Versuch" (Besson & Niggli 1991), was to compare different cropping systems on a model scale. They were designed as crop rotation experiments with replications. In recent years European (Heidmann 1988; Häni & Vereijken 1990; Vereijken & Royle 1989; Vereijken 1992) and American (Anderson 1992; Robbins 1989) researchers who are working on cropping systems development tend more and more to carry out experiments at the commercial farm level. Distinctive features of this method are the holistic and dynamic approach, which means the use of complete farm systems as experimental units. Instead of using a fixed experimental layout, attention is paid to a continuous improvement of the farming systems.

The aim of the Apelsvoll Cropping System Experiment is to study nutrient and pesticide leaching as well as yields, yield quality and economy at the cropping system level, and the systems should be improved with regard to environmental impacts. To do so, traditional experimental methods as well as the systems approach are utilized. Six different cropping systems replicated once were established as "model farms", distributed within a 6 x 2 grid of approximately 3 ha. Each model farm is equipped as a field lysimeter for measuring both drainage and surface runoff. This experimental layout is suited to comparisons of the cropping systems, and it gives possibilities for improvement of the individual systems.

This article presents a detailed account of the experimental layout of the Apelsvoll Cropping System Experiment. The possibilities and limitations of the methodology used in the experiment are discussed as compared to those of full-scale cropping systems experiments.

MATERIALS AND METHODS

The site and climate

The experimental site is located at Apelsvoll Research Station, Kapp, which is situated in the central part of southeast Norway (60° 42' N, 10° 51' E, and approximately 250 m a.s.l.). The experimental area slopes gently towards the north (Fig. 1.).

According to the classification by Critchfield (1966), Apelsvoll has a humid continental climate with long and cold winters, and cool summers (Table 1). Usually there is snow from the middle of November to the middle of April. The length of the period with frozen ground and the depth of frost varies between years, but the ground is usually frozen in the period with snow. The depth of frost is normally less than 50 cm. The average

starting date of the growing season (diurnal temperature greater than 6°C) is May 3 and the end date is October 5.

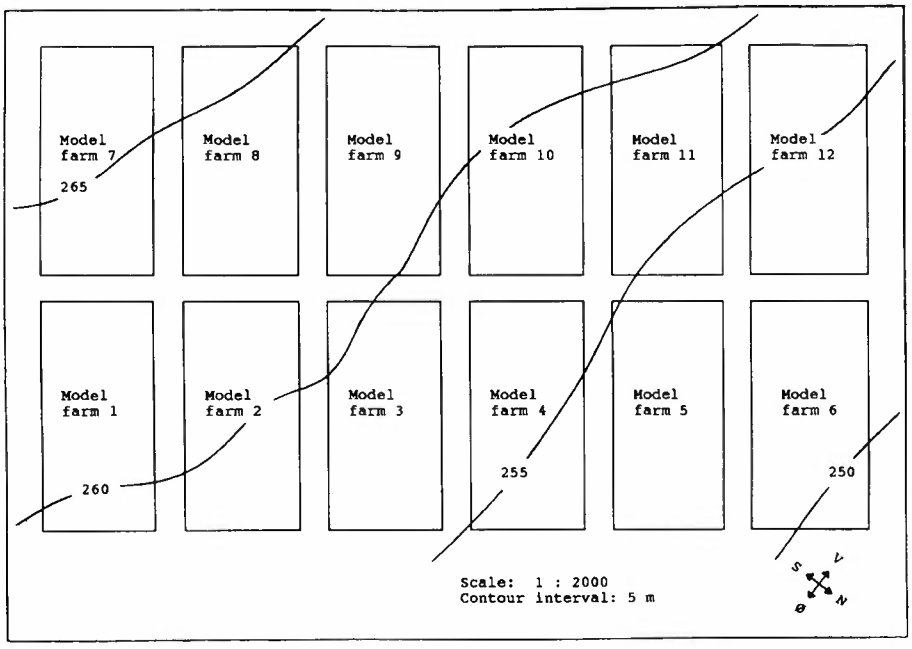

Fig. 1. Elevation and slope conditions for the experimental area

The annual precipitation is fairly low (600 mm), more than 50% of which occurs during the growing period May-September. There is usually a dry period with a water deficit and need for irrigation in May/June. At the end of the growing season and in the long period with no plant growth, there is a surplus of precipitation which gives rise to the erosion and nutrient leaching problems which are discussed by Eltun (1994a), Eltun (1994b) and in future articles in this journal.

The major soil groups, described more fully by Riley & Eltun (1994), are well- or imperfectly drained brown earth (Orthic melanic brunisols and gleyed melanic brunisols) which are typical of the region. The dominant soil textures are loam and silty sand, with a humus content of about 6% in the topsoil.

Table 1. Mean air temperature, precipitation, potential evaporation, days with frost and days with snow cover at Apelsvoll

Month	Temperature[1] °C	Precipitation mm	Evaporation[2] mm	Days with frost[3] 10 cm	20 cm	50 cm	Days with snow cover [4]
January	-7,4	37		25	8	0	31
February	-7.0	26		21	4	3	28
March	-2.5	29		14	1	3	30
April	2.3	32		2	0	0	19
May	9.0	44	64	0	0	0	1
June	13.7	60	85	0	0	0	0
July	14.8	77	82	0	0	0	0
August	13.5	72	66	0	0	0	0
September	9.1	66	40	0	0	0	0
October	4.6	64		0	0	0	2
November	-1.3	53		30	0	0	15
December	-5.3	40		15	8	0	28
May-Sept.	12.0	319	336	0	0	0	1
Year	3.6	600		80	21	6	154

[1] Temperature, precipitation and evaporation in the mean for the years 1961-90

[2] Loss of water from a Thorsrud evaporation pan with a surface area of 0.25 m^2 at Apelsvoll substation Kise, 10 km distant. [3] Days with frost at 10, 20 and 50 cm soil depth in the mean for the years 1987-93. [4] Mean for the years 1957-87

Cropping history

The experimental area was forested until 1935, when the trees were cut and the area was used as pasture land. In 1954 the land was reclaimed as part of a reclamation experiment aimed at comparing the stone removal capacity of different machines (Haugen et al. 1975). No drainage system was established as part of the reclamation work, but there were some old stone ditches and shallow drains in the area. The results from that experiment revealed that stones accounted for 9-16% of the total volume of topsoil (0-20 cm), and the soil is still stony today.

After reclamation, the field was again used as pasture until 1975. During the period 1975-85 the field was cropped with a 6-year rotation including barley/oats, potatoes/root crops, barley, 3-year ley; regular amounts of mineral fertilizer and an average of 10 tonnes slurry/ha/year were applied (Bakken 1982).

Different kinds of experiments were carried out at this location until 1985, after which the field was uniformly managed, lying fallow in 1986 and 1988 and under winter wheat in 1987. The summer of 1988 was used for mechanical stone removal to a depth of 10 cm and weed control by harrowing, and in August the laying of the dainage pipes on the experimental area was commenced.

The 1989 season was used for a "uniformity" trial with barley and undersown grass over the whole area except for the model farms under conversion to ecological farming, where a green manure crop was grown. The purpose of this trial was to assess the natural variability of the soil. The experiment with model farms was established in 1990.

Cropping systems, experimental layout and cropping management

Six cropping systems with the following types of farming, were defined for the first experimental period (1990-93):

A. Conventional arable cash crop production without farmyard manure: application of mineral fertilizer and pesticides according to current recommendations by the extension services and autumn ploughing on all plots.

B. Integrated arable cash crop production without farmyard manure: reduced inputs of mineral fertilizer, ploughless soil tillage and the use of pesticides strictly according to observed requirements.

C. Ecological arable cash crop production with some farmyard manure: management according to the principles for ecological farming where the nutrient supply is based on a small herd of beef cows.

D. Conventional forage crop production with farmyard manure: maximum amount of farmyard manure permitted by official legislation, application of slurry in the autumn followed by autumn ploughing, total amounts of fertilizer and pesticide management according to current recommendations by extension services.

E. Integrated forage crop production with farmyard manure: reduced inputs of farmyard manure and mineral fertilizer, application of all slurry at the start of or during the growing season, spring ploughing and the use of pesticides strictly according to observed requirements.

F. Ecological forage crop production with farmyard manure: management according to the principles for ecological farming with milk production.

As shown in Fig. 2, each cropping system is represented on two trial blocks or model farms of 0.18 ha randomly distributed within a 6 x 2 grid of 3.3 ha. Each model farm has eight rotation plots. All the crops in a particular rotation are thus present each year.

The crop rotations and system differences with regard to fertilization, soil tillage, plant protection, cultivars and seeding rates in the period 1990-93 are presented in Tables 2-5. The conventional and integrated cash crop systems involve early potatoes in the rotation. This provides a good opportunity for the sowing of winter wheat, but early potatoes are not typical of arable cash crop farming in the area. The differences in crop rotation within the arable cash crop farms and within the forage crop systems are kept as small as possible.

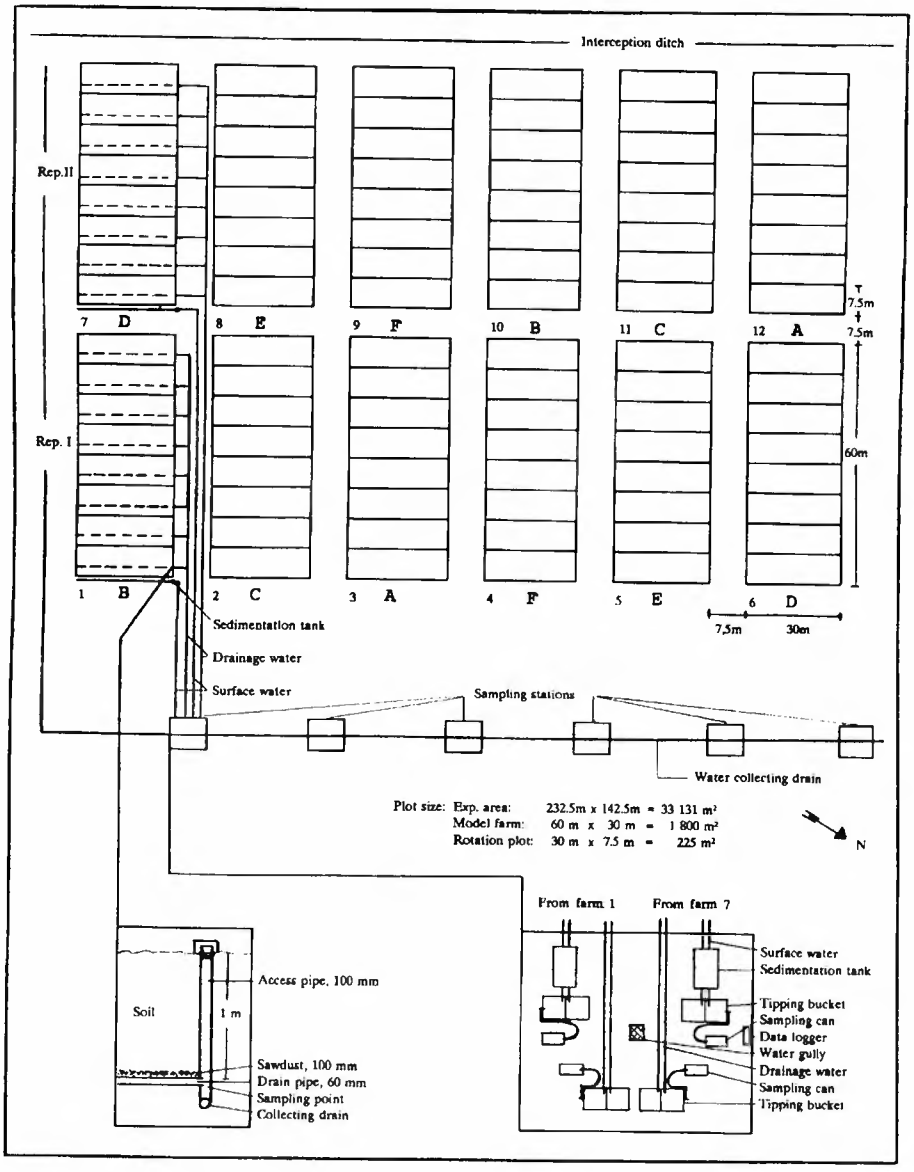

Fig. 2. Experimental layout showing the model farms with rotation plots. Each model farm has a drainage system for water sampling identical to those shown for farms 1 and 7

Table 2. Crop rotation and cultivation methods for the cropping system "Conventional arable cash crop production without farmyard manure" (A) and "Integrated arable cash crop production without farmyard manure" (B) for the years 1990-93

Crop-rotation	Mineral fertilizer kg/ha and % N-P-K[4]		Soil tillage		Pesticides[1] liter (kg)/ha and trade name[2]			
	Spring	Summer	Spring	Autumn	Herbic.	Growth reg.	Fungic.	Insectic.
Conventional (A)								
Early potatoes/ winter wheat	1100/ 11-5-17		Harrow	Harrow	0.75/ Sencor		1.0/ Sportak	
Winter wheat	530/ 21-4-10	200/calcium nitrate		Plough	3.0/ Actril 3	1.5/ CCC 750	1.0 x 2/ Tilt Top	1.0/ Rogor
Oats	530/ 21-4-10		Harrow	Plough	2.5/ Actril 3	1.5/ CCC 750		1.0/ Rogor
Barley	570/ 21-4-10		Harrow	Plough	2.5/ Actril 3		0.5/ Tilt	1.0/ Rogor
Late potatoes	1000/ 11-5-17		Harrow	Plough	0.75/ Sencor	2.5/ Reglone	1.5 x 2/[3] Dithane	0.5/ Sumicidin
Spring wheat	480/ 21-4-10	200/calcium nitrate	Harrow	Plough	2.5/ Actril 3	1.5/ CCC 750	1.0 x 2/ Tilt Top	1.0/ Rogor
Oats	530/ 21-4-10		Harrow	Plough	2.5/ Actril 3	1.5/ CCC 750		1.0/ Rogor
Barley	570/ 21-4-10		Harrow	Plough	2.5/ Actril 3		0.5/ Tilt	1.0/ Rogor
Integrated (B)								
Early potatoes winter wheat	630/ 11-5-17		Plough	Harrow			1.0/ Sportak	
Winter wheat	340/ 21-4-10	130/calcium nitrate			1.0/ MCPA 750		1.0/ Tilt Top	0.15/ Pirimor
Oats	350/ 21-4-10		Harrow		1.0/ MCPA 750			
Barley	350/ 21-4-10		Harrow		1.0/ MCPA 750			
Late potatoes	600/ 11-5-17		Plough				1.5/[3] Dithane	
Spring wheat	290/ 21-4-10	130 calcium nitrate	Harrow		1.0/ MCPA 750		0.5/ Tilt	0.15/ Pirimor
Oats	350/ 21-4-10		Plough		1.0/ MCPA 750			
Barley	350/ 21-4-10		Plough		1.0/ MCPA 750			

[1] The spraying plans are justified according to the actual requirement each year

[2] ISO names:
Sencor - metribuzin, Actril 3 - ioxynil + dichlorprop + MCPA, CCC 750 - chlormequat, Reglone - diquat, Sportak - phrochloraz, Tilt Top - propiconazol + fenpropimorph, Tilt - propiconazol, Dithane M-45 - mancozeb, Rogor L20 - dimethoat, Sumicidin 10 FW - fenvalerat, MCPA - MCPA, Pirimor G - pirmicarb, Ridomil MZ - metalaxyl + mancozeb

[3] 2.5/Ridomil MZ

[4] In addition to N-P-K, the compound fertilizer 11-5-17 contains 2.5% Ca, 1.8% Mg, 9% S and 0.02% B, and 21-4-10 contains 1.8% Ca, 1.2% Mg, 2.7% S, 0.02% B and 8.2% Cl

Table 3. Crop rotation and cultivation methods for the cropping system "Conventional forage crop production with farmyard manure" (D) and "Integrated forage crop production with farmyard manure" (E) for the years 1990-93

Crop-rotation	Mineral fertilizer kg/ha and % N-P-K[3]		Slurry tonnes/ha			Soil tillage		Herbicides[1] 1(kg)/ha, trade name[2]
	Spring	Summer	Autumn	Spring	Summer	Spring	Autumn	
Conventional (D)								
Barley/ undersown grass	320/ 25-3-6		40			Harrow		3.0/ Basagran - MCPA
1st year ley	670/ 18-3-15	200/ 22-2-12			20			
2nd year ley	380/ 22-2-12	190/ 22-2-12		20	20			
3rd year ley	380/ 22-2-12	190/ 22-2-12		20	20		Plough	
Fodder-beet		400+ 350/ calcium nit.	50	50		Harrow	Plough	2.0/Pyramin + 4.0/Betanal
Spring wheat	250/ 25-3-6	200/calcium nitrate		20		Harrow	Plough	2.5/Actril 3
Oats	300/ 25-3-6			20		Harrow	Plough	2.5/Actril 3
Green fodder		550/calcium nitrate	30	50		Harrow	Plough	
Integrated (E)								
Barley/ undersown grass				30		Plough		2.5/Basagran
1st year ley	450/ 18-3-15	170/ 18-3-15			10			
2nd year ley	280/ 18-3-15	110/ 18-3-15		20	10			
3rd year ley	280/ 18-3-15	110/ 18-3-15		20	10			
Fodder-beet		320/calcium nitrate		50		Plough		5.0/Betanal
Spring wheat	160/ 25-3-6			20		Plough		1.0/MCPA
Oats	100/ 25-3-6			20		Plough		1.0/MCPA
Green fodder		200/calcium nitrate		50		Plough		

[1] There are no growth regulators in these systems, and the fungus and insect treatments are the same as those for systems A and B (Table 2)

[2] ISO names: Basagran - MCPA - bentazone + MCPA, Pyramin DF - chloridazon, Betanal - phenmedipham, Basagran - bentazone

[3] In addition to N-P-K, the compound fertilizer 25-3-6 contains 1.7% Ca, 1.0% Mg, 1.3% S, 0.02% B and 5% Cl, and 18-3-15 contains 1.3% Ca, 1.5% Mg, 3.8% S, 0.02% B and 10.6% Cl, while 22-2-12 contains 1.1% Ca, 1% Mg, 2.1% S, 0.02% B and 9% Cl

Table 4. Crop rotation and cultivation methods for the cropping system "Ecological arable cash crop production with some farmyard manure" (C) and "Ecological forage crop production with farmyard manure" (F) for the years 1990-93

Crop-rotation	Mineral fertilizer kg/ha and type	Slurry, tonnes/ha		Soil tillage		Plant protection
		Spring	Summer	Spring	Autumn	
Ecological cash crop (C)						
Barley/undersown clover grass	300/sulphate of potash-magnesia	10		Plough		Weeding as necessary
Clover grass						
Spring wheat/ undersown crop		20		Plough		Harrowing
Late potatoes	400/sulphate of potash-magnesia	10		Plough		Ridging/ weeding
Barley/undersown clover grass	300/sulphate potash-magnesia	20		Plough		Weeding as necessary
Clover grass/ winter wheat					Plough	
Winter wheat/ undersown crop		10				Weeding as necessary
Oats/ undersown crop				Plough		Harrowing
Ecological forage crop (F)						
Barley/undersown grass		20		Plough		Weeding as necessary
1st year ley		10	10			
2nd year ley		10	10			
3rd year ley		10	10			
Fodder-beet		40		Plough		Hoeing
Green fodder		20		Plough		
Spring wheat/ undersown crop		20		Plough		Harrowing
Oats/peas		20		Plough		Harrowing

The amounts of nitrogen, phosphorus and potassium fertilizer applied in the conventional systems were determined according to recommendations given by the extension services (Eriksen 1990), soil mineral nitrogen measurements (N-min) and soil analysis, while the amount of fertilizer in the integrated systems was reduced by 30-40% as compared to the conventional systems. To reduce the risk of potassium deficiency in the ecological arable cash crop system, some potassium was applied in sulphate form (Table 4).

Table 5. Varieties, seed mixtures and seeding rates for the different cropping systems and crops in the years 1990-93

Cropping system	Crop	Species	Variety	Seeding rate, kg/ha
All	Cereals	Winter wheat	Kalle	200
systems		Oats	Kapp	200
		Barley	Tyra	220
		Spring wheat	Bastian	230
F	Cereal/peas mix.	Oats	Kapp	120
		Peas	Helka	80
A and B	Early potatoes		Rutt	3000
A and B	Late potatoes		Troll	3000
C	Late potatoes		Danva	3000
D, E and F	Fodder-beet		Kyros	50000 plants
C	Clover grass	Timothy	Grindstad	20
		Alsike clover	Alpo	3.7
		Red clover	Pradi	1.2
	Undersown crop	White clover	Huia	5
		Perennial rye-grass	Tove	15
D and E	Ley	Timothy	Grindstad	13.7
		Meadow fescue	Salten	7.5
		Red clover	Bjursele	3.7
	Green fodder	Fodder-rape	Emerald	8
		Oats	Kapp	80
		Italian rye-grass	Meritra	20
		Peas	Poneka	80
F	Ley	Timothy	Grindstad	11.2
		Timothy	Bodin	2.5
		Meadow fescue	Salten	6.2
		Red clover	Bjursele	1.7
		Red clover	Pradi	1.7
		Alsike clover	Alpo	0.7
		White clover	Milkanova	0.7
	Undersown crop	White clover	Huia	5
		Perennial rye-grass	Tove	15
	Green fodder	Fodder-rape	Emerald	4
		Oats	Kapp	80
		Peas	Poneka	90
		Italian rye-grass	Meritra	20
		Vetch	Jaga	40

Farmyard manure was applied as wet-composted cow slurry with the following composition (percentage of wet weight, mean of 4 years and range):

Dry matter: 6.4 (4.5-7.9)
Total nitrogen: 2.7 (1.8-3.3)
Ammonium nitrogen: 1.7 (1.5-2.0)
Phosphorus: 0.5 (0.5-0.6)
Potassium: 3.8 (3.2-4.4)

The area assumed per animal, and the amount of manure used in the forage crop systems was as follows:

Conventional: 0.4 ha per animal manure unit = 45 t slurry/ha
Integrated: 0.6 ha per animal manure unit = 30 t slurry/ha
Ecological: 0.8 ha per animal manure unit = 22 t slurry/ha

The amount of farmyard manure in the ecological arable cash crop system (C) was 2.5 ha per animal manure unit, giving 9 t slurry/ha. The slurry was divided between the crops as shown in Tables 3 and 4. In the integrated and ecological systems all the slurry was spread in the spring and summer, while in the conventional system 30% was applied in the autumn. When used for ley and winter wheat, the slurry was mixed with water in a 2:1 proportion.

Straw was removed from the field in autumn from all systems, and a rotary tiller was used for spring harrowing in the integrated cash crop system. For conventional soil tillage a two-furrow reversible plough was used in the autumn and in spring an S-tine harrow was used. The cereals on the ecological model farms were harrowed by a weed harrow before seeding of the undersown crop. A rear-wheel drive tractor with a weight of 2.8 t was used for all soil tillage and other management operations, while plot harvesters were used for yield recording. The experimental area is equipped with a "rain-gun" irrigation machine, with which the entire area can be irrigated when necessary. The "Televis" extension service system (Magnus et al. 1991) was used to determine the need for fungicides and insecticides in cereals.

The yield of each rotation plot was calculated as the mean of four harvest plots of 9 m^2.

The plan is to maintain the experiment for at least two rotations (16 years), and it is presently funded until the end of 1996.

The lysimeter installation

Each model farm has a separate drainage system (Fig. 2), from which leaching water is measured continuously by means of tipping buckets coupled to a "Delta" data logger, and sampled for chemical composition proportionally to the runoff on a monthly basis. The surface runoff is measured in the same way, while the erosion material is collected in soil sedimentation tanks.

The drainage pipes were placed at a depth of 1 m and covered with a 10 cm layer of sawdust. The distance between the pipes was 7.5 m and each pipe was placed 2.5 m from the lowermost plot border. To reduce the risk of horizontal flow of water from outside the experiment, a 1.7 m deep ditch was dug at the upper border of the experimental area. The ditch wall facing the experiment was covered with plastic and the ditch was filled with stones. A 1 m deep interception drain was laid along the southeastern border.

In addition, water leached from separate rotation plots can be sampled for chemical composition by means of access pipes (Fig. 2), and in autumn and spring the soil is sampled to a depth of 50 cm for measurement of mineral nitrogen (nitrate and ammonium) content (N-min) on selected rotation plots. Each bulked soil sample of about 0.5 l consists of 10 auger samples and there are two replications.

Measurements

Annual registrations are made of the following variables (more details about the variables and measuring methods will be given in the articles dealing with the results):

Weather (at a standard, automatic weather station 200 m to the southeast of the field):
- air temperature 10 and 200 cm above ground and soil temperature at 10, 20 and 50 cm depths;
- precipitation and snow depth;
- open surface water evaporation (May-September) from a Thorsrud evaporation pan with a surface area of 0.25 m^2 at Apelsvoll substation Kise, 10 km distant;
- global radiation, relative humidity, wind speed 200 cm above ground and sunshine duration.

Runoff:
- total soil losses, total water runoff, pH, total nitrogen, nitrate, ammonium, total phosphorus, total dissolved phosphorus, phosphate, calcium, magnesium, and sulphate. These measurements are performed in both drainage and surface water;
- concentration measurements of dichlorprop, MCPA, metribuzin, propiconazol, dimethoat and fenvalerat in the summer and autumn;
- nitrate concentration in the drainage water from separate rotation plots - mineral nitrogen (N-min) at 0-50 cm soil depth on selected rotation plots.

Yield:
- standard yield and quality measurements for all crops;
- content of nitrogen, phosphorus, potassium, magnesium, calcium and sodium in all crops.

Special yield quality measurements:
- NIRR-analysis of feeding value variables such as protein content, digestibility, crude fibre and water soluble carbohydrates;
- cadmium in cereals and potatoes;
- mycotoxins (deoxynivalenol, 3-acetyl-DON, fusarenon-X and nivalenol) in cereals;
- content of MCPA, diclorprop, propiconazol and dimethoat in cereals and metribuzin and mancozeb in potatoes.

Weeds and pests:
- weed occurrence on selected rotation plots every fourth year;
- selected fungi and insects in cereals and potatoes.

Data from the experiment are also used for economic analyses and nutrient balance calculations, and studies on polyfage predators in cereals, earthworms and microbial biomass and activity are going on in the cropping systems. Groundwater movement in the experimental area and nutrient losses to the groundwater are also examined in a special study.

DISCUSSION

The conversion to ecological farming was made simultaneously on all fields in 1989. It was assumed that it takes time before the soil becomes adapted to the new conditions. The ecological farms are thus designated as being in the conversion stage at least during the first 4-year period. Owing to the position of the ecological model farms within the experiment (Fig. 2) and the small size of the farms, even the best management practice cannot totally prevent edge-effects of operations, such as insect control, on the other cropping systems.

The idea behind this experiment is to simulate existing and future cropping systems by means of model farms, and to measure the impact of the systems with regard to effects on the environment, yield quality and economy. There are, however, various limitations with regard to the validity of such model cropping systems that have to be taken into account when interpreting the results. It is difficult to make small-scale models that are representative of real farms, and site-specific conditions such as climate, soil and runoff conditions limit their representativity. Another problem is that, despite considerable effort, the management of the model farms cannot be identical to real farm situations.

Because of these limitations more attention should be paid to relative differences between the systems within the experiment than absolute differences between the experiment and commercial cropping situations. The knowledge gleaned from the project about the differences between the systems, and how management factors influence these differences can then be used for improving agricultural management in on-farm situations.

Improvement of the cropping systems requires a gradual changing of the management factors. This can be done as a step-by-step operation, which means that the cropping systems will be changed at certain intervals, for instance at the start of each new crop rotation period. The changing of the cropping systems will depend upon the experiences gained in the project and other relevant information. The effect of the changes may be measured by comparing the differences between the systems before and after the changes have taken place.

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The Apelsvoll cropping system experiment II. Soil characteristics

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Soil chemical and physical properties were studied in 1988 prior to the start of the Apelsvoll Cropping System Experiment, in which the productivity and environmental side-effects of six cropping systems are studied in a field-scale lysimeter comprising 12 model farms, each of 0.2 ha. Only small differences were found between these units in topsoil reaction, contents of plant available nutrients (P, K, Mg, Ca) and trace elements (Cu, B, Mn, Zn, Fe, Mo, Cd). Organic carbon and total nitrogen content varied somewhat between individual units, but was on average similar for the six cropping systems. The same was true for most of the soil physical parameters studied, including texture, water storage capacity, air capacity, air permeabilty and saturated hydraulic conductivity. Variability in soil physical conditions increased generally with depth, and some trends were found in transport-related properties in different parts of the site. A uniformity trial in 1989 revealed that grain yield levels are likely to be affected in dry years by the available water capacity of the topsoil. The effect of soil variability on the results of the six cropping systems may therefore be minimized by ensuring that adequate irrigation is given.

Key words: Air permeability, available nutrients, available water capacity, saturated hydraulic conductivity, soil organic matter, soil variabilty, trace elements.

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The Apelsvoll Cropping System Experiment (Eltun 1994) is aimed at comparing the environmental impact, productivity, yield quality and economic efficiency of six cropping systems. Each system is represented on two "model farms" of 0.2 ha, randomly distributed within a 6 x 2 grid of approximately 3 ha on gently sloping farmland. Each model farm is equipped as a field lysimeter for measuring both drainage and surface runoff. In order to ensure an accurate interpretation of research findings at this site, it is essential that any systematic variation in soil properties between different parts of the experimental area be known at the outset. This is particularly important in view of the relatively low degree of replication which is possible in studies of this kind. Moreover, such initial information is

necessary in order to assess possible effects which the cropping systems may have on soil properties in the future.

This article presents results of soil chemical and physical investigations carried out in 1988 at the time when the drainage measurement system (described by Eltun 1994) was installed.

BACKGROUND INFORMATION

The soils at Apelsvoll Research Station have been systematically mapped and described by Bakken (1982). They are developed on morainic till, dominantly derived from the Cambro-Silurian shales and limestones which are found in the region. The experimental site overlies a syncline in which shale is folded between ridges of Ordovician limestone. The morainic material is rich in harder rocks (mainly gneisses, schists, quartzites and some gabbro) transported from the north and west. Fluvioglacial deposits of coarse-grained material occur frequently in patches. Soil reaction normally increases with depth, reflecting the high base content of the parent materials and the leaching nature of the climate.

The major soil groups are well- or imperfectly drained brown earths (Orthic melanic brunisols and gleyed melanic brunisols, after the Canadian system of soil classification employed at the Norwegian Institute of Land Inventory). The dominant soil textures are loam and silty sand, with a high humus content in the topsoil. Bakken (1982) found that humus levels for the whole farm had declined on average from 6.3% to 5.8% between 1954 and 1980, presumably as a result of more frequent arable cropping and possibly also due to deeper tillage. The subsoil is generally compact by nature, and most root water uptake is normally confined to the upper 70 cm of such soils (Riley 1989).

An extract of Bakken's soil map, showing the situation of the cropping system experiment, is presented in Fig. 1.

MATERIALS AND METHODS

Soil chemical properties

Total nitrogen, organic carbon and ignition loss were measured in sieved (<2 mm) material from bulked core samples taken at five depths from each of the 24 profiles sampled for physical analyses (see next section). Total nitrogen was measured by Kjeldahl distillation, organic carbon by means of a Cenco carbon analyser and ignition loss by combustion at 550°C for 4 h. Organic matter was assumed to be equal to organic carbon multiplied by 1.72.

Soil reaction, plant-available nutrients and trace elements were measured in random soil samples taken in autumn 1988 from the topsoil (0-30 cm) in each of the 96 rotation plots. Each bulked sample of about 0.5 l consisted of 10 auger samples.

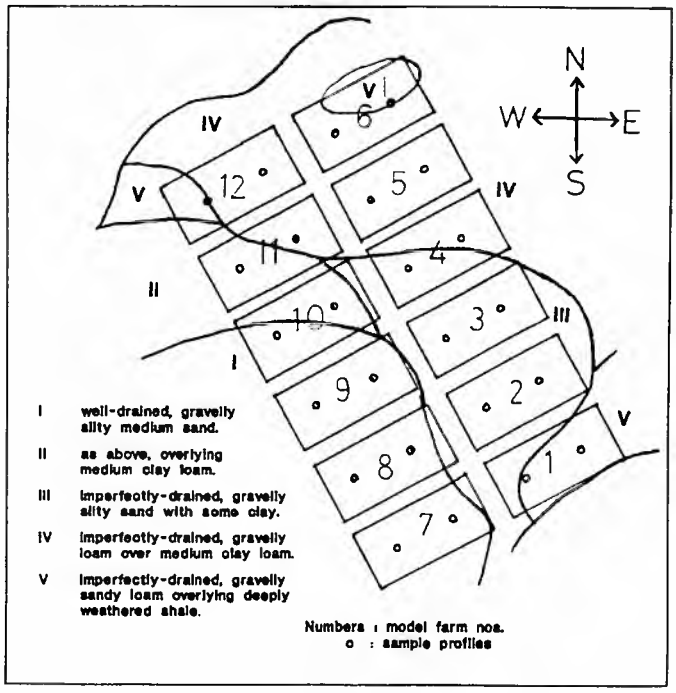

Fig. 1. Soil map of the site of the Apelsvoll cropping system experiment, showing the location of the sample profiles

The soil reaction (pH) was measured in a 1:2.5 soil:water suspension. Plant available phosphorus, potassium, manganese and calcium were determined after extraction with a mixture of ammonium lactate and acetic acid (Egner at al. 1960). Acid soluble potassium was measured by flame photometry after extraction with 1 N nitric acid. Boron was measured by flame photometry after extraction in boiling water. The trace elements copper, manganese, zink, iron, molybdenum and cadmium were measured by means of a graphite furnace atomic absorption spectrophotometer, using the following extraction solutions:

Fe: ammonium acetate + acetic acid
Cu: sodium salt of EDTA + ammonium chloride
Mn: manganese nitrate
Mo: ammonium oxalate + oxalic acid
Zn: hydrochloric acid
Cd: hydrochloric acid + nitric acid

All soil chemical analyses were performed at the Agricultural Service Laboratory of the Norwegian Centre for Soil and Environmental Research.

Soil physical properties

Two undisturbed 100 cm^3 core samples were taken in each of five horizons at ca. 15 cm depth intervals down to 70 cm from 24 soil profiles, arranged in a 6 x 4 grid, with ca. 33 m equidistance in each direction. The depth of horizon no. 2 was adjusted upwards to avoid the topsoil/subsoil boundary which occurred at a depth of 20-27 cm. The profiles were located on subplot nos. 2 and 6 of model farms in replicate I, and nos. 3 and 7 in the case of replicate II (see Eltun 1994, fig. 2). Their proximity in relation to Bakken's mapping units is shown in Fig. 1.

Moisture retention at pF values of 2, 3 and 4.2 was measured using standard pressure plate/membrane equipment and soil mechanical analyses were performed using Elonen's (1971) pipette method. Total soil porosity was calculated from the relationship between dry bulk density and mean particle density. The latter was estimated from a relationship with ignition loss which has been found for morainic loam soils in the region (Riley 1988), and a value of 2.65 was assumed for gravel and small stones:

$$\text{Particle Density} = 2.72 - 0.014 * \text{Ign.loss} \quad (n=176,\ R^2=0.76)$$

Air permeability was measured in samples equilibrated at pF 2, using apparatus described by Green & Fordham (1975). Saturated hydraulic conductivity was estimated from a relationship found locally with air permeability at pF 2 (Riley & Ekeberg 1989):

$$K_{water} = 0.106 * K_{air}^{1.31} \quad (n=229,\ R^2=0.86)$$

where K stands for the intrinsic permeability constant of either fluid. Hydraulic conductivities (k_{sat}) are quoted here in centimetres per hour at 10°C, which is close to the average soil temperature for the period April-September.

All soil physical analyses were carried out at Apelsvoll Division Kise.

RESULTS AND DISCUSSION

Soil chemical properties

Mean contents of both total nitrogen and organic carbon show an abrupt decline between topsoil and subsoil, and are relatively uniform within these horizons (Table 1). The C:N ratio is approximately 10:1, as expected (Fig. 2).

Table 1. Mean values and standard deviations of total nitrogen, organic carbon and ignition loss percentages

	Total nitrogen		Organic carbon		Ignition loss	
Depth	Mean	Std.dev.	Mean	Std.dev.	Mean	Std.dev.
5-10 cm	0.277	0.045	2.66	0.49	7.38	0.87
20-25 cm	0.258	0.075	2.54	0.73	6.96	1.54
35-40 cm	0.048	0.019	0.37	0.02	2.24	0.69
50-55 cm	0.045	0.008	0.26	0.06	2.24	0.62
65-70 cm	0.044	0.006	0.23	0.07	2.13	0.55

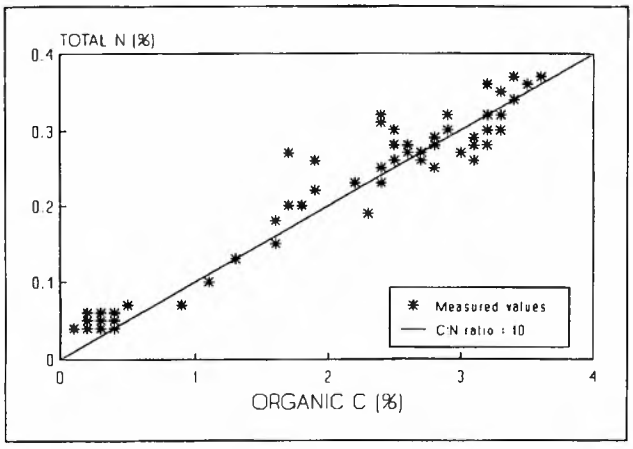

Fig. 2. Relationship between total N and organic C in soil

There are some differences between individual model farms in the trial (Table 2). In particular it should be noted that both of the southernmost model farms (nos. 1 and 7, Fig. 1) have the lowest organic matter content. Nevertheless, the average figures for cropping systems are generally similiar.

The variation in organic matter content is considered unlikely to cause appreciable variation in nitrogen mineralization rates, but it may have some effects on physical soil properties. This is examined in the next section.

A regression equation was calculated for the estimation of organic matter content from ignition loss and clay content:

Org. mat. (%) = 0.81 x Ign.-loss (%) - 0.038 x Clay (%) - 0.70

The equation accounted for 97% of the variation in organic matter. The effect of clay was almost identical to that found in a previous study in Sweden (Kälvesten 1975), but the present equation gives somewhat lower organic matter values than the Swedish equation. Subsequent investigations have shown that the present equation gives good representation of the differences between measured organic matter and ignition loss for a wide variety of soils throughout Norway (Riley 1993).

As can be seen from Table 3, there are only small differences between individual model farms and cropping systems with regard to soil reaction and available phosphorus. The variation is somewhat greater for available potassium, manganese and calcium and for acid soluble potassium. Some of the differences between model farms and cropping systems in the case of potassium and calcium contents are statistically significant.

Table 2. Mean values of total N, organic C and ignition-loss percentages in topsoil and subsoil for individual model farms and cropping systems

	Topsoil (0-30 cm)			Subsoil (30-70 cm)		
Model farm	Tot. N	Org. C	Ign.loss	Tot. N	Org. C	Ign.loss
1	0.17	1.8	5.2	0.04	0.2	1.7
2	0.28	2.9	7.6	0.06	0.4	3.0
3	0.25	2.4	6.8	0.04	0.2	2.3
4	0.25	2.2	7.0	0.04	0.3	2.3
5	0.28	2.9	7.7	0.04	0.4	2.2
6	0.27	2.7	7.4	0.05	0.3	2.5
7	0.25	2.4	6.3	0.05	0.3	1.9
8	0.27	2.8	7.0	0.04	0.3	1.7
9	0.30	2.5	7.8	0.05	0.3	2.2
10	0.34	3.3	8.1	0.05	0.2	2.0
11	0.25	2.5	7.1	0.05	0.3	2.3
12	0.32	2.8	8.1	0.04	0.3	2.4
Std. error	0.035	0.36	0.77	0.006	0.06	0.09
Crop system						
A1B1	0.28	2.6	7.5	0.04	0.3	2.3
A1B2	0.25	2.6	6.7	0.04	0.2	1.9
A1B3	0.26	2.7	7.3	0.05	0.4	2.7
A2B1	0.26	2.5	6.8	0.05	0.3	2.2
A2B2	0.28	2.9	7.4	0.04	0.3	2.0
A2B3	0.27	2.4	7.4	0.04	0.3	2.2
Std. error	0.025	0.23	0.54	0.004	0.05	0.23
Mean	0.27	2.6	7.2	0.05	0.3	2.2

The measured differences within the experiment with regard to pH values and available macronutrients are considered unlikely to have any significant effect on growth conditions, with the possible exception of potassium which has a low content in this soil, or on the predisposition of the site for nutrient leaching.

The differences in the content of the trace elements manganese and iron were somewhat greater than those for copper, boron, zink, molybdenum and cadmium (Table 4). Nevertheless, the levels of all these elements appear to be within the ranges normally found in cultivated soil in Scandinavia (Andersson 1992; Låg 1989).

The content of the heavy metals cadmium, zink and copper is well below the permissible limits for agricultural use of sewage sludge in Norway. The cadmium content is close to the average level found in recent investigations of cadmium content of cultivated soils in southeast Norway (Singh 1990; Gullord 1994).

Table 3. Mean values of soil reaction and plant-available nutrients in topsoil (0-30 cm) for individual model farms and cropping systems

Model farm	pH	P-AL	K-AL	K-HNO_3	Mg-AL	Ca-AL
			mg/100 g air dry soil			
1	6.1	6.9	7.5	27	10.5	206
2	6.2	6.0	6.4	25	10.0	245
3	6.2	9.3	8.3	35	12.2	232
4	6.2	8.2	5.5	25	10.4	257
5	6.3	9.4	9.4	43	12.5	225
6	6.2	9.5	8.8	35	9.8	247
7	6.3	7.6	8.2	37	12.5	252
8	6.0	7.8	7.6	34	10.2	255
9	6.3	6.2	5.3	25	11.0	240
10	6.4	6.8	6.0	26	10.2	237
11	6.5	7.8	6.4	29	14.0	282
12	6.3	7.5	6.3	26	10.6	260
Std. error	0.2	1.5	1.8	2	3.7	8
Crop system						
A1B1	6.2	8.4	7.4	31	11.5	246
A1B2	6.2	6.9	6.8	27	10.4	222
A1B3	6.4	6.9	6.4	28	12.0	264
A2B1	6.2	8.5	8.5	37	11.1	250
A2B2	6.2	8.6	8.5	39	11.3	240
A2B3	6.3	7.2	5.4	26	10.7	249
Std. error	0.2	1.0	0.7	3	1.2	11
Mean	6.3	7.7	7.2	31	11.1	245

Soil physical properties

General description

The soil is of a loam texture in almost 80% of all cases (Table 5, Fig. 3). Some profiles have layers of medium silty sand in the subsoil, and there are a few cases with medium clay loam at depth. The gravel content is somewhat higher in the subsoil than in the topsoil, and the total porosity shows an abrupt decline below the ploughing depth (Fig. 4). This may be associated with the absence of tillage and the considerably lower levels of organic matter. Anthropogenic soil compaction is not thought to have played a role in this soil.

Table 4. Mean values of trace elements in topsoil (0-30 cm) for individual model farms and cropping systems

Model farm	Cu	B	Mn	Zn	Fe	Mo	Cd
				mg/kg air dry soil			
1	2.8	0.57	44	4.1	171	1.35	0.17
2	2.5	0.61	51	3.2	148	1.67	0.15
3	2.7	0.61	48	3.4	146	1.30	0.13
4	2.7	0.77	62	3.6	178	1.42	0.15
5	2.7	0.56	42	3.6	137	1.34	0.13
6	3.0	0.69	64	3.5	164	1.52	0.19
7	3.3	0.62	51	4.0	177	1.38	0.19
8	3.0	0.70	44	3.9	118	1.59	0.24
9	3.0	0.51	48	3.4	171	1.57	0.17
10	3.8	0.61	50	3.6	131	1.61	0.25
11	3.6	0.66	85	4.8	218	1.56	0.19
12	3.6	0.78	85	4.2	248	1.63	0.25
Std. error	1.1	0.20	4	1.5	89	0.30	0.10
Crop system							
A1B1	3.2	0.70	67	3.8	197	1.47	0.20
A1B2	3.3	0.59	47	3.9	151	1.48	0.21
A1B3	3.1	0.64	68	4.1	183	1.61	0.18
A2B1	3.2	0.66	58	3.8	171	1.45	0.20
A2B2	2.8	0.63	43	3.7	128	1.46	0.19
A2B3	2.9	0.64	55	3.5	174	1.49	0.16
Std. error	0.2	0.10	10	0.4	27	0.10	0.02
Mean	3.0	0.64	56	3.8	167	1.49	0.18

Table 5. Mean values for soil mechanical analysis at different depths (n = 24)

Depth (cm)	Clay[1]	Silt[1]			Sand[1]			Gravel[2]
		Fine	Medium	Coarse	Fine	Medium	Coarse	
5-10	18	8	14	13	20	20	7	7
20-25	17	8	13	14	21	20	7	7
35-40	12	8	14	15	22	21	8	13
50-55	17	8	12	14	21	20	8	12
65-70	16	8	13	13	21	20	9	12

[1] Mass % of fine earth (< 2 mm)
[2] Mass % of bulk sample

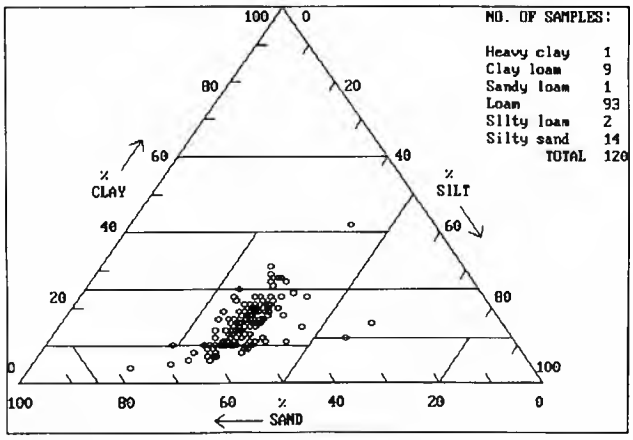

Fig. 3. Distribution of soil samples within the textural triangle used in Norway, and associated class names

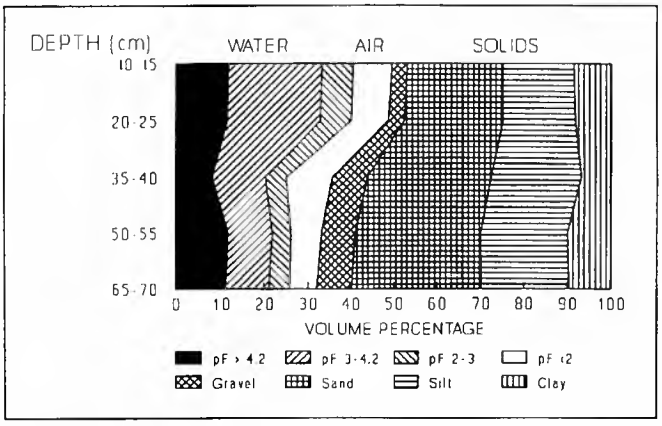

Fig. 4. Depth/volume diagram showing average distribution of pore space and solids at different profile depths

The soil's storage capacity for plant-available water (pF 2-4.2) is high in the topsoil, but considerably lower in the subsoil. Most of the available water is relatively strongly held, with only about one quarter in the "readily available" range (pF 2-3). The soil's air capacity (measured at pF 2) is moderately high, even in the subsoil, but air permeability and hydraulic conductivity are both low, below a depth of 40 cm (Fig 5).

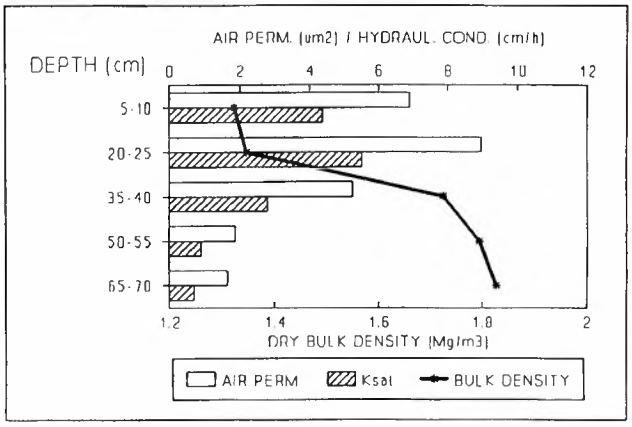

Fig. 5. Average values at different soil depths for air permeability at pF2, saturated hydraulic conductivity and dry bulk density

Variability in physical properties

Coefficients of variation within each horizon are presented in Table 6 for the major variables measured. Total porosity shows little variation within horizons. Silt and sand contents are relatively stable, but gravel content shows higher variability at all depths, as does clay content below 40 cm. Transport parameters for air and water are, as expected, extremely variable.

Table 6. Coefficients of variation (%) for major soil physical parameters at different depths

Depth (cm)	Clay	Silt	Sand	Gravel	Porosity	Avail. water	Air cap.	Air perm.	K_{sat}
5-10	16	8	10	36	9	9	38	119	158
20-25	20	11	13	69	9	14	37	61	80
35-40	29	16	14	47	9	13	30	79	98
50-55	52	13	23	39	11	24	73	185	263
65-70	52	18	21	41	9	31	63	135	186

In view of the general similarity of soil horizons within the topsoil and within the subsoil, mean values for these two groupings have been calculated for each of the 12 model farms, and for each of the six cropping systems. These are shown in Tables 7 and 8, together with the relevant standard errors, calculated from analysis of variance.

Table 7. Mean values of selected soil physical parameters in topsoil (0-30 cm) for individual model farms and cropping systems

Model farm	Parameter number 1	2	3	4	5	6	7	8	9	10
1	46	14	8	23	9	5	12	55	31	14
2	50	8	7	30	13	4	5	45	35	20
3	49	11	15	27	12	11	6	46	36	18
4	46	5	6	28	13	3	9	49	33	18
5	50	7	10	30	13	6	4	43	36	21
6	48	7	4	28	13	2	8	45	36	20
7	47	11	13	26	11	9	10	49	34	17
8	50	9	4	30	11	2	6	47	37	17
9	52	9	12	32	11	8	7	52	34	15
10	50	7	4	32	12	2	7	50	34	17
11	49	7	7	30	12	4	6	47	35	19
12	52	9	6	31	12	3	6	40	41	20
Std. error	2.2	1.5	3.3	1.6	1.0	2.7	2.5	2.9	1.5	2.1
Crop system										
A1B1	51	10	11	29	12	7	6	43	38	19
A1B2	48	10	6	27	11	3	9	52	33	15
A1B3	49	7	7	30	12	4	6	46	35	19
A2B1	48	9	8	27	12	5	9	47	35	19
A2B2	50	8	7	30	12	4	5	45	36	19
A2B3	49	7	9	30	12	6	8	50	33	17
Std. error	1.5	1.2	2.5	1.2	0.5	2.1	1.5	1.5	1.0	1.0
Mean	49	9	8	29	12	5	7	47	35	18

Parameter number:

1. Total porosity (%)
2. Air capacity at pF2 (%)
3. Air permeability at pF2 (μm^2)
4. Total available water (pF 2-4.2) (%)
5. Non-available water (pF >4.2) (%)
6. Hydraulic conductivity (cm/h)
7. Gravel content (%)
8. Sand content (%)
9. Silt content (%)
10. Clay content (%)

Table 8. Mean values of selected soil physical parameters in subsoil (30-70 cm) for individual model farms and cropping systems

Model farm	Parameter number 1	2	3	4	5	6	7	8	9	10
1	37	16	7	16	5	4	11	62	31	7
2	33	8	4	13	13	2	13	49	33	19
3	35	10	4	15	10	2	15	53	32	15
4	33	3	1	17	13	<1	10	49	34	19
5	33	9	2	14	11	<1	15	49	35	16
6	32	6	1	11	15	<1	11	42	36	22
7	34	10	3	17	7	1	14	56	34	10
8	34	10	4	16	8	2	13	52	37	11
9	32	6	2	15	11	1	15	50	36	15
10	32	7	4	14	11	2	13	52	33	15
11	34	6	2	17	11	<1	7	47	39	14
12	35	6	2	18	12	<1	10	41	41	19
Std. error	1.7	1.9	2.2	1.9	2.6	1.4	1.6	4.9	2.7	4.0
Crop system										
A1B1	35	8	3	17	10	1	12	47	36	17
A1B2	34	11	5	15	8	3	12	57	32	11
A1B3	33	7	3	15	12	1	10	48	36	17
A2B1	33	7	2	14	11	<1	12	49	35	16
A2B2	34	9	3	15	9	1	14	51	36	13
A2B3	33	5	2	16	12	<1	12	49	35	17
Std. error	1.3	1.4	1.6	1.2	1.7	1.0	1.2	3.6	1.6	2.7
Mean	34	8	3	15	10	<2	12	50	35	15

Parameter number:

1. Total porosity (%)
2. Air capacity at pF2 (%)
3. Air permeability at pF2 (μm^2)
4. Total available water (pF 2-4.2) (%)
5. Non-available water (pF >4.2) (%)
6. Hydraulic conductivity (cm/h)
7. Gravel content (%)
8. Sand content (%)
9. Silt content (%)
10. Clay content (%)

Two model farms (nos. 1 and 7) both at the upper, southeasterly end of the site, stand out from the rest with lower water-holding capacity and a somewhat higher sand content. As mentioned above, they also have the lowest levels of organic matter (Table 2). Another trend is discernible at the lower, northernmost corner of the site, where the clay content is generally higher, whilst air and water transport parameters have somewhat lower values than elsewhere.

Average values for the six cropping systems, which are represented by four profiles each, show little difference between treatments in either water storage or transport parameters. Two of the model farms which exhibit the greatest extremes in soil physical conditions (nos. 6 and 7, in opposite corners of the site) have the same cropping system (A2B1).

Relationships between variables

The available water storage capacity of the topsoil shows a close positive correlation with organic matter content (Fig. 6), whilst in the subsoil it is negatively correlated with both clay content and dry bulk density and positively correlated with silt content. The amount of non-available water is in both cases closely related to the soil's clay content (Fig. 7). The following regression equations, in which all variables are statistically significant, were derived for these parameters:

Topsoil: (n=48)

% avail. water = 15.1 + 3.1 * org.mat.% (r^2=0.80)

% non-avail. water = 4.5 + 0.41 * clay% (r^2=0.72)

Subsoil: (n=72)

% avail. water = 40.1 + 0.30 * clay% - 16 * bulk density + 0.23 * silt% (R^2=0.60)

% non-avail. water = 7.6 + 0.64 * clay % (r^2=0.92)

Overall: (n=120)

% avail. water = 10.6 + 3.6 * org.mat.% + 0.22 * silt% - 0.33 * clay% (R^2=0.89)

% non-avail. water = 1.2 + 0.60 * clay % (r^2=0.90)

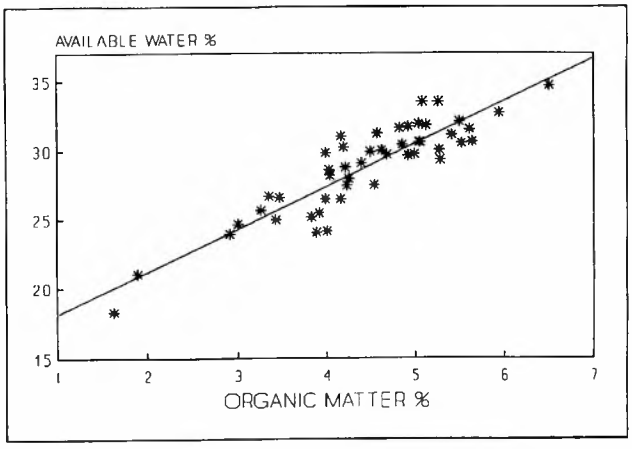

Fig. 6. Relationship between available water holding capacity (pF 2-4.2) and organic matter content in the topsoil

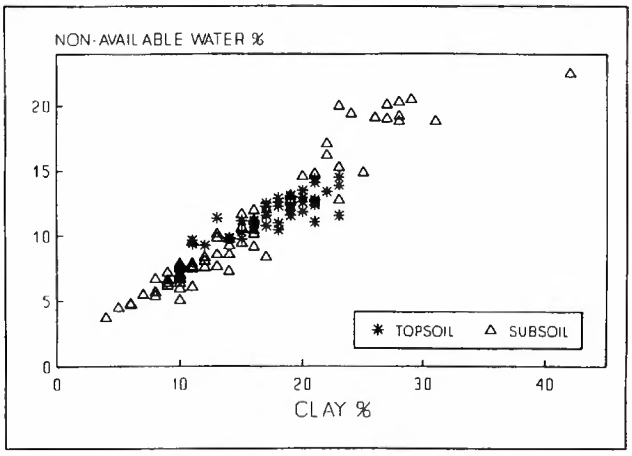

Fig. 7. Relationship between non-available water-holding capacity (pF >4.2) and clay content in topsoil and subsoil

Transport properties for air and water are positively correlated with the air capacity of the soil, and negatively related to dry bulk density, as might be expected. The relationship with clay content is not clear-cut, due to these properties' high variability. The air capacity of the subsoil is, however, negatively correlated with its clay content. The trend in these parameters down-slope across the site (from southeast to northwest) is shown in Fig. 8, using average data from two adjacent model farms in each case.

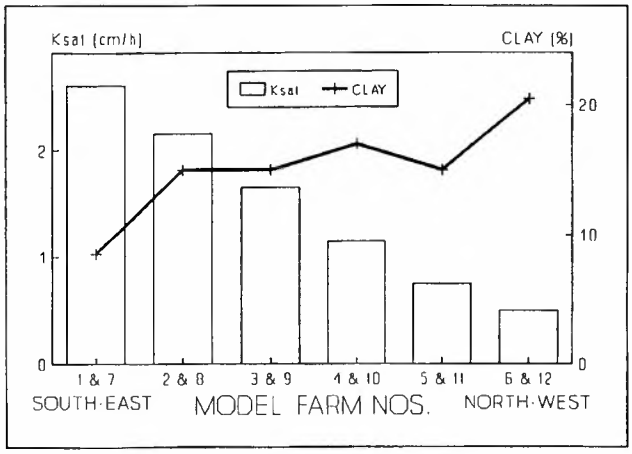

Fig. 8. Mean values of saturated hydraulic conductivity (Ksat) and clay percentage in the subsoil of model farms grouped from southeast to northwest

Soil variation and potential crop productivity

A uniformity trial performed in 1989, in which barley was grown on all model farms except those under conversion to ecological systems, provided yield data with which it is possible to evaluate possible effects of soil variability on productivity. The potential rainfall deficit in May and June was somewhat higher than normal in that year, but was lower than normal in July. Under such conditions it is to be expected that yield levels would be affected by the soil's water-holding capacity.

A strong correlation was found between barley grain yield in the dummy trial and the available water-holding capacity of the topsoil ($r=0.89^{***}$, Fig. 9). There was also a correlation, although a much weaker one ($r=0.59$), with the content of fine material (silt+clay) in the subsoil. However, inclusion of the available water in the subsoil did not improve the relationship with yield, presumably because increasing clay content reduces water availability.

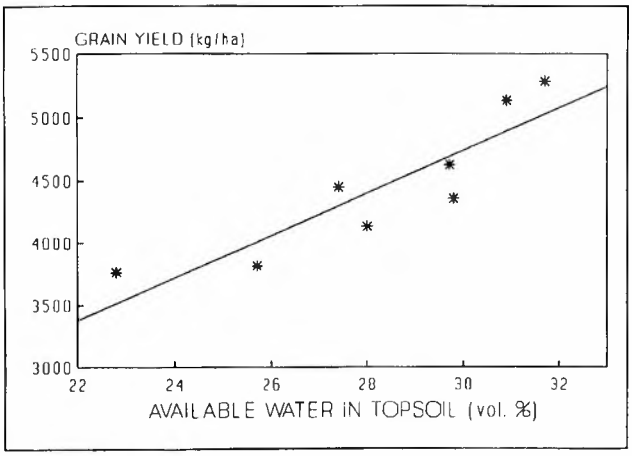

Fig. 9. Relationship between barley grain yields in 1989 and available water-holding capacity in the topsoil

Expected "uniformity" yield levels were calculated for all blocks and for the average of each cropping system, on the basis of the regression equation between yield and available water in the topsoil (Y = 170 * AWC% - 350). The results in Table 9, shown both in kg/ha and relative to the mean, suggest that, despite some variation between individual model farms, there is no significant overall difference in inherent soil productivity of the model farms used to represent the six cropping systems.

Table 9. Relative crop productivity of indivdual model farms and cropping systems, calculated on the basis of a a dummy trial in 1989 in which yields were related to the available water capacity of the topsoil

Model farm	Barley yield kg/ha	Rel.yield %	Model farm	Barley yield kg/ha	Rel.yield %
1	3516	77.6	7	4009	88.5
2	4672	103.1	8	4689	103.5
3	4298	94.9	9	5012	110.6
4	4417	97.5	10	5012	110.6
5	4706	103.8	11	4757	105.0
6	4400	97.1	12	4893	108.0

Cropping system		Barley yield kg/ha	Relative yield %
A1B1	Conventional/arable	4595	101.4
A1B2	Integrated/arable	4264	94.1
A1B3	Ecological/arable	4715	104.1
A2B1	Conventional/mixed	4205	92.8
A2B2	Integrated/mixed	4698	103.6
A2B3	Ecological/mixed	4715	104.0
Std. error of difference		330	7.3

SUMMARY

The results of this study of the chemical and physical properties of the soil at the start of the Apelsvoll Cropping System Experiment confirm that the soil is representative of the morainic loam soils which surround Lake Mjøsa in the northern part of Norway's most important arable region. The soil is fertile and well suited for the growing of a wide range of crops. Its present condition with regard to nutrient content and soil reaction is favourable.

The soil exhibits a fairly high degree of variability with regard to physical properties, but this is a typical trait of soils throughout the area. Variability in the topsoil is mainly associated with organic matter content, which plays an important role in the moisture-holding capacity of the soil. Variability in the subsoil is associated with clay content, which probably affects air and water transport properties.

On the whole, the soil is not strongly prone to drought, but some variation in the productivity of individual model farms may be expected in dry years. For this reason it is to be recommended that the site be irrigated under such conditions. This is representative of common practice for most crops in the area surrounding Lake Mjøsa. The relationship found between crop productivity and soil water-holding capacity gives grounds for covariance correction of yields, but it is unlikely that the same relationship applies in years with differing drought intensity.

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